TOEPASSING VAN NATUURLIJKE VEZELS IN COMPOSIET-MATERIALEN

NRLO-rapport nr. 90/18

Een studie uitgevoerd in opdracht van de Nationale Raad voor Landbouwkundig Onderzoek door Chem Systems International Ltd.

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juni 1990

VOORWOORD

In het kader van de werkzaamheden van de Stuurgroep Agrificatie is door de NRLO een opdracht verstrekt aan Chem Systems International Ltd. te Londen om een verkennende marktgeoriënteerde studie te verrichten naar de toepassingsmogelijkheden van natuurlijke vezels in composiet-materialen. De studie is begeleid door de Werkgroep Vezels van de Stuurgroep Agrificatie, onder voorzitterschap van Dr. W. André de la Porte.

Het U hier aangeboden rapport is het resultaat van deze studie. Wij hopen dat de studie het inzicht in de marktmogelijkheden voor natuurlijke vezels in composiet-materialen heeft verbreed.

Dr.Ir. A.P. Verkaik,
Secretaris NRLO.

NATURAL FIBRE
REINFORCED COMPOSITES

A Study Prepared

for

The National Council for

Agricultural Research

of the Netherlands

February 1990

CONTENTS

I EXECUTIVE SUMMARY

A. INTRODUCTION

The objective of this study is to provide the members of the working party of the NRLO with an assessment of the market opportunities for natural fibres in composites. The definition of natural fibre is basically restricted to plant fibre available in Northern Europe. Composites are assumed to consist of fibre as reinforcement in a matrix of either polymer or cement. Thus strawboard made by compressing straw under heat, which releases natural resins, is not strictly a composite. Similarly wood flour filled polypropylene, whilst it is a composite, does not rely on the wood fibre for reinforcement, and is thus excluded from the analysis, as is cellulose fibre filled melamine and chipboard made from particles of wood glued together with thermoset adhesives.

The survey was prepared by conducting interviews with contacts identified by literature review. A listing of the most useful contacts is provided in Appendix II.

The results of the analysis are summarised below and it is concluded that there is a market of about 650 000 metric tons for natural fibres used in Western Europe to make about 810 000 metric tons of various types of composites.

B. GLASS FIBRE COMPOSITES

As a reference point for this analysis it should be noted that the market for glass fibre reinforced composites is slightly over 1 million metric tons per year, which uses about 420 thousand metric tons of glass fibre. The demand is rising at about 8 percent per year, mainly for thermoset composites in the transportation and electrical/electronics industries. The market is dominated by West Germany with about 27 percent market share. The most common processing techniques are injection moulding (both thermoplastic and thermoset, sheet moulding compound and hand layup of GRP (e.g. for small boats).

Glass fibre is well established in the industry because it is a consistent product that can be made in different materials with different coatings to suit different matrices. The industry is well supported by both big multinational glass producers and major petrochemical companies that develop resin systems. Glass fibre has replaced natural fibres in many applications because of its product uniformity and ready availability.

C. NATURAL FIBRE COMPOSITES

The natural fibres reviewed here are:

- Straw
- Jute
- Cotton
- Hemp
- Flax
- Other fibres such as Coir, Sisal, Pineapple
- Wood fibre

Straw is a waste product that is often burnt by farmers concerned to **kill pests** in the field at minimum expense. There is environmental pressure to reduce burning, and a paper making process has been developed to use straw. In less developed countries straw/clay composites are used for housing, but in Europe the only such development is the Terre Paille project near Lyon in France. The use of straw in cement slabs is declining as wood wool is replacing it.

The major composite board using straw is the Stramit straw board process which is used to produce about 30 000 metric tons per year of insulation panels. The market is not growing significantly, as more consistent products, such as plywood, chipboard and blockboard are preferred by the building industry.

Jute is mainly used for sacking and carpet backing and is under threat from polypropylene. The Unido/Winfield/Madras project developed a jute/polyester resin composite for low cost housing but no evidence was found of such composites being used in Europe. Research work is being done by the jute industry to improve the bonding between jute and polyester resin. This research could be applicable to miscanthus fibres.

About 4 000 metric tons of **Cotton** is used in Europe for two types of composite where it gives good reinforcement and impact strength. There is a fairly mature market for cotton reinforced laminates using phenolic or epoxy resins. The sheet, rod or tube is machined to make items such as circuit board supports, bearing surfaces, yacht pulleys. This sector faces competition from injection moulded glass reinforced thermoplastics. Moulding compounds based on cotton fibre and thermosetting resins such as urea formaldehyde and unsaturated polyester are used for compression moulding of impact resistant electrical fittings.

Hemp is widely used for rope, textiles and paper but no evidence was found of its being used in composites.

Flax is widely grown in Europe (about 75 000 hectares in 1988 yielding 33 000 metric tons of flax yarn for textiles). Further increase in acreage is being encouraged by the EC. The prime product is the high quality fibre for textiles and cigarette paper, but large quantities of flax residues are produced, and these are used in composites. Flax fibre board (often containing wood fibre as well) is made by at least nine companies in Europe. It is estimated that 45 000 metric tons of flax fibre residue (shives) is used, and the demand is beginning to outstrip supply. Flax is used in a small way for cement boards where it replaces asbestos. Eternit are developing the product and use about 100 metric tons of flax for this application.

Other fibres such as coir, sisal, banana leaf and pineapple leaf are being experimented with in the less developed countries. The motivation is to use indigenous waste products to save imports of glass or use of asbestos. Items such as chairs, crash helmets and even wash basins are being developed. However, there is little evidence that such fibres will be imported into Europe for use in composite manufacture in Europe. The transportation cost cancels out the low basic value, some sisal is being imported by Eternit for trials for fibre cement board.

Wood fibre is used in medium density fibre board (MDF). The binder is a thermoset resin such as phenol formaledehyde. The current production is about 850 000 m^3 (620 000 metric tons) and capacity is being increased to about 3.4 million cubic metres by 1992. The usage of flax residue fibre in MDF is about 2.5 percent (i.e. 15 500 metric tons).

D. END-USE MARKETS

The market for natural fibre reinforced composites is not sufficiently developed to make it feasible to prepare a comprehensive matrix of demand by type. The end uses covered by this analysis are discussed below.

Audio/video uses of fibre board are declining as injection moulded thermoplastic replaces it. Glass fibre has largely replaced natural fibre in **Electrical Appliances** due to its more consistent properties and freedom from moisture content. Cotton and wood flour composites are still used in the **Transportation** sector for sound insulating mat and door lining panels. The **Building and Construction** industry is a major user of natural fibre composites, typically strawboard, wood fibre MDF and a small amount of fibre reinforced cement. The alkalinity of the cement preventing fibre decay. However, polypropylene and special glass fibre are also being developed for this asbestos replacement market. The main use for MDF is the **Furniture** industry, which uses it for cabinets, desk carcasses, unit tops and loudspeaker cases.

Other minor uses for strawboard and fibre board are **Consumer** products such as knobs and housewares and **Industrial** products such as pallets, crates and highly technical cotton filled laminates. The **Medical** sector turns out not to use natural fibre composites in spite of being a big user of linen for sterilisable sheets.

E. PROSPECTS FOR NATURAL FIBRE COMPOSITES

There are two basic markets for natural fibres in composites. Firstly the low cost low specification product where untreated fibre is used as a filler and weak reinforcing agent. This covers straw boards and cement board, and miscanthus could well find applications here. The second market is the true specification composite where special binders and surface treatment is used to create good bonding. This is the area of cotton/phenolic laminates and medium density fibre board. Here the natural fibres are at a disadvantage versus glass, carbon fibre, and polypropylene as they are not consistent in quality and have an inherent moisture content that affects processability. Flax residues are used in MDF, and presumably so could miscanthus. However, the higher specification products do not seem worth the technical effort needed to make miscanthus acceptable.

There is considerable research work being done to investigate and improve natural fibres, the key areas of work are:

- Chemical modification of fibre surfaces.
- Process improvement to recover elementary fibre.

Most of the work is addressed to the uses of natural fibres in textiles, paper or ropes, not as composites. However, the Biocomposites Centre at University of Wales is involved in this area of work.

The only research work we found being done on miscanthus fibre was at Wageningen, and this is at an early stage, with the emphasis on the use of miscanthus as a paper pulp.

Natural fibres are being developed outside Europe, but imports into Europe are erratic due to political and harvest problems. Thus European producers of composites are unlikely to rely on imported fibre. However, if a regular supply of consistent fibre were available (as it is for flax residues) then manufacturers such as Eternit would be interested.

F. CONCLUSIONS

The estimated usage of natural fibres in composites in Western Europe is shown in Table I.F.1

TABLE I.F.1
SUMMARY OF NATURAL FIBRE USAGE IN COMPOSITES IN WESTERN EUROPE 1989
(metric tons)

Fibre	Product	Tonnage Fibre	Tonnage Composites	Comments
Straw	Stramit	30 000	30 000	slow growth.
Jute	-	nil	-	some in India.
Cotton	Laminates	500	1 000	no growth.
Cotton	Moulding Compounds	3 500	10 000	low growth.
Hemp	-	nil	-	only in textiles.
Flax	Fibre Board		90 000	steady growth.
Flax	Fibre Cement	100	500	Eternit doing trials.
Wood	Medium Density Fibre	620 000	680 000	growing rapidly.
Total		**6 541 00**	**811 500**	

The market as defined is dominated by wood fibre, if this and straw are eliminated the market is a more modest 20 thousand metric tons, compared to the 422 thousand metric tons of glass fibre used in composites.

The key conclusions are:

- Natural fibres are losing out to synthetic fibres for high specification applications because they are more consistent and their manufacture is supported by major global companies.

- The use of Flax fibre (shives) residue is increasing in fibre board.

II INTRODUCTION

A. STUDY OBJECTIVES

1. Background

The National Council for Agricultural Research of the Netherlands has established working groups to study specific areas which could be relevant to large scale use of Dutch agricultural products in industry. The Working Group in charge of fibres wishes to analyse the opportunities for natural fibres in composites. Chem Systems was commissioned to assist them by carrying out a preliminary survey on the use of natural fibres in composites in Western Europe.

2. Objective

The opportunities in Western Europe for natural fibres in composites are reviewed.

3. Scope of Work

The key fibres considered are those that can be grown in Northern Europe such as:

- Straw
- Flax
- Hemp
- Miscanthus

Notice is taken of other fibres that may be used.

The considered market areas are:

- Electrical/Electronic
- Transportation
- Building/Construction

- o Furniture
- o Consumer Products
- o Industrial products
- o Medical products

The key questions discussed in the study are:

- o What areas are of interest and should be researched further?
- o What is the status of scientific and technical development in Europe, in the US and India?
- o Are non European natural fibres competing with European fibres?
- o What problems could hinder the introduction of natural fibres in composites?

B. APPROACH

The assignment was carried out by first doing an in-depth literature search. This yielded information on the use of flax and jute in composites but nothing on miscanthus. The desk research was supplemented by telephone enquiries, and visits to contacts established by the search. Appendix II lists those organisations that provided useful information and could be helpful to NRLO in a later stage of the project.

There is very little hard evidence of a market for natural fibres in composites, so the estimates given in the analysis were based on information gleaned from several sources.

III GLASS FIBRE COMPOSITES

A. INTRODUCTION

As a reference point for this survey of prospects for natural fibre composites, a brief survey of the glass fibre composite business is provided.

B. THE MARKET

The European glass fibre composites market reached a record level of 1 095 000 metric tons in 1988. During the past ten years the market has almost doubled and the growth rate was about 13.8 percent in 1988. The demand for glass fibre in Western Europe reached 422 000 metric tons in the same period; the growth rate was about 12 percent, slightly below the average for composites as there is a trend towards cheaper fillers.

About 75 percent of the total West European market can be attributed to four countries: Germany, Italy, France and UK.

65 percent of this same market was processed either by compounding, hand lay-up or sheet/bulk moulding using either thermoplastics or thermosets (primarily unsaturated polyester resins).

The two main market segments are the electrical/electronic industry and the transportation market. They are followed by the building industry and the industrial and agricultural equipment. Consumer goods and sport and leisure are also noted but their size is small, however they are often the innovative sectors.

Figures III.B.1 to III.B.3 summarise the West European market for glass fibre composites.

The future for glass fibre composites still looks bright, the growth rate is expected to have been in the range of 8 to 10 percent in 1989. The forecast for 1990 is in the same range. The excellent results either obtained in 1988 or forecast for 1989 and 1990 are due to the conjunction of the economic growth which has followed the recession in the first half of the 1980s, the high level of investment, the increasing amount of composite material in cars and, the growing needs of the electronic industry sector. The marine construction and building industries have increasingly moved towards the use of glass fibre composites to replace conventional materials such as steel and aluminium.

From the technical point of view, the glass fibre composite business is not mature, new products have been offered to the market as new transformation processes were developed; Glass Mat Thermoplastic (GMT), Resin Transfer Moulding (RTM), long glass fibre compounds, Reinforced Reaction Injection Moulding (RRIM).

The only threat could come from laws on styrene emission in hand lay-up and spray-up workshops. The styrene emission can be reduced but the competitiveness of the process will be affected.

The glass fibre composite business combines the expertise of the major global glass companies with the resin expertise of the well established petrochemical companies. Thus the R&D capability is high and the global standards are strict. This effectively means that natural fibres, which have variable properties depending on crop conditions, are unlikely to pose a serious threat to the glass fibre industry.

Figure III.B.1

West European Market 1988
Glass Reinforced Composites

Market share by country (percent)

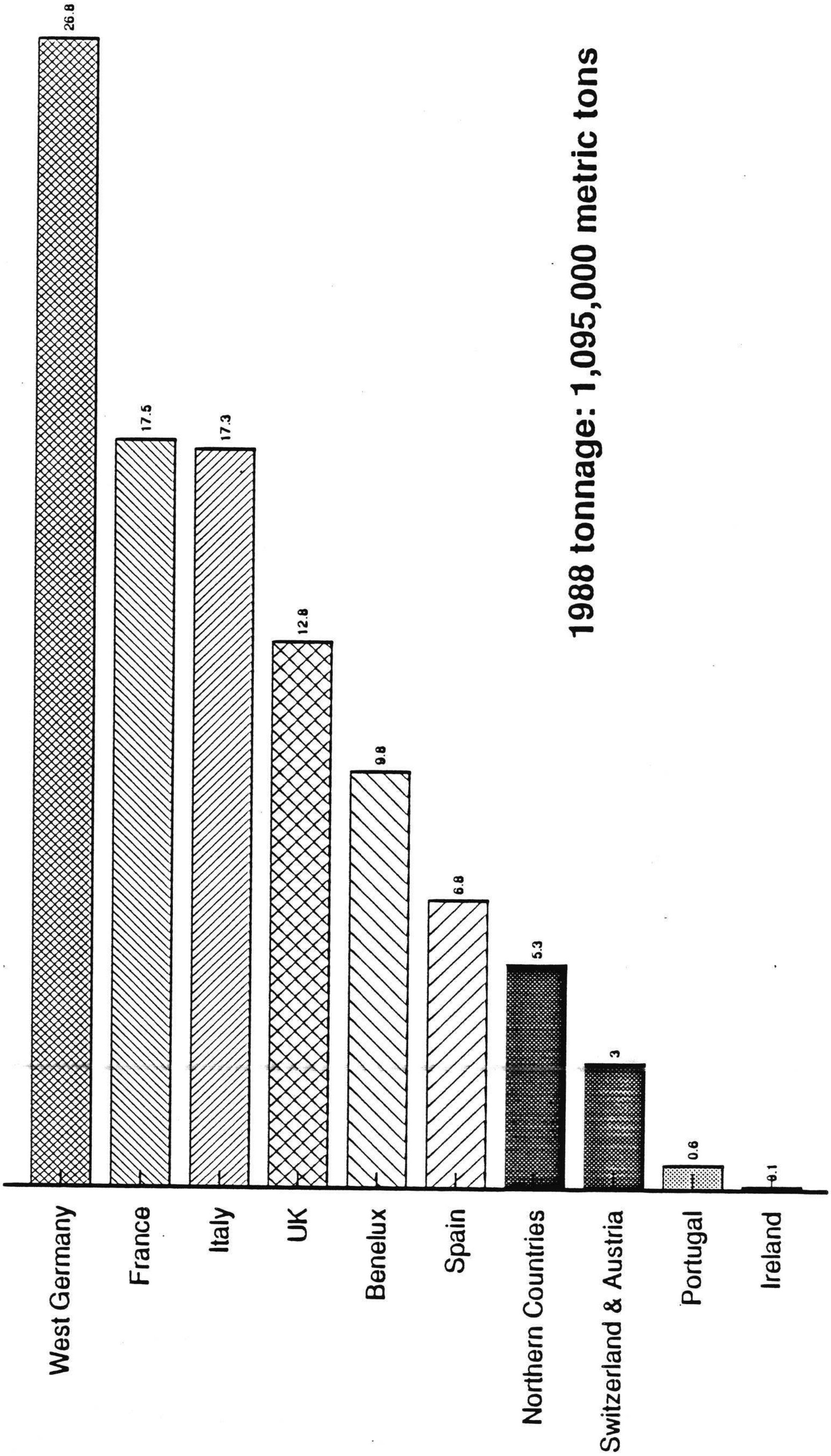

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Figure III.B.2

West European Market 1988
Glass Reinforced Composites

Breakdown by end-use (percent)

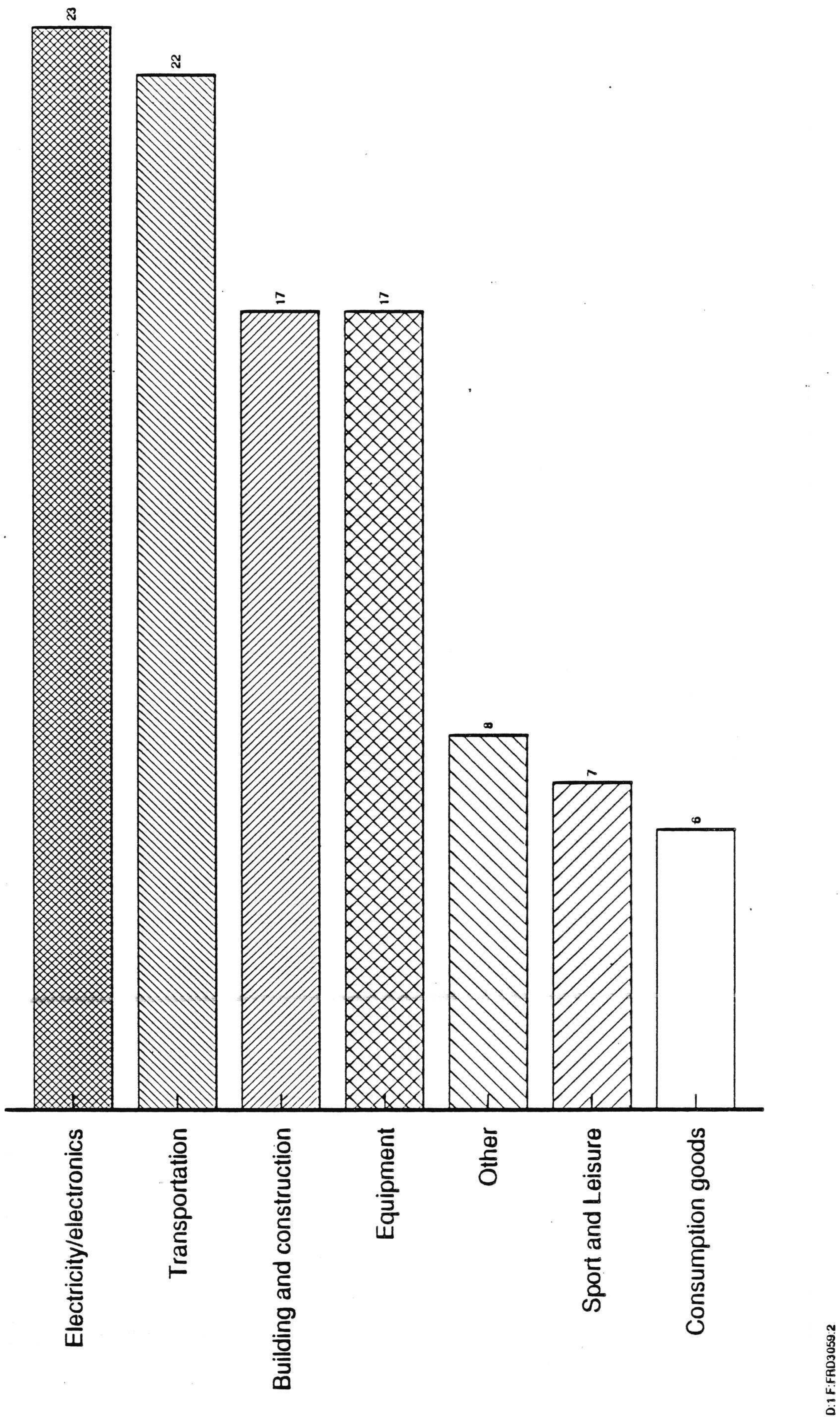
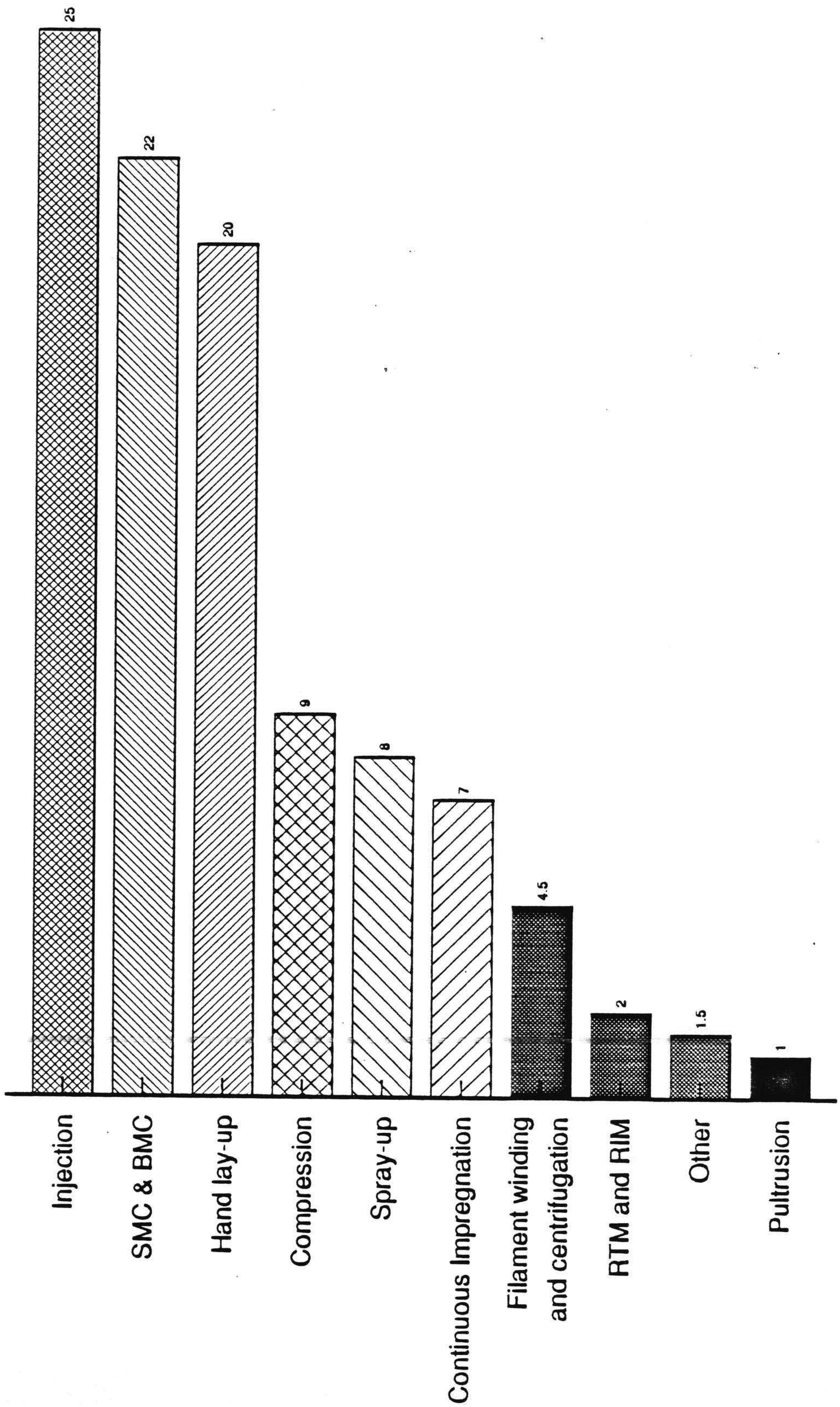


Figure III.B.3
West European Market 1988
Glass Reinforced Composites
Breakdown by fabrication process (percent)



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IV NATURAL FIBRE COMPOSITES

A. INTRODUCTION

Composites are defined as materials where the fibre is a reinforcing part of a combination of binder matrix and fibre. Thus loosely bonded insulating board made from compressed straw is excluded and wood flour filled thermoplastics, where the wood is a non-reinforcing filler, are also excluded, as is the particle board made out of wood chips.

Not much is known about natural fibres with regard to their specific properties, as reinforcement materials. However, the following values, from various authors, have been found in the literature and show that the natural fibres have lower tensile strength and modulus compared to man-made fibres, but they do have the advantage of lower density.

TABLE IV.A.1

Units	Specific Gravity	Tensile Strength GN/m^2	Specific Tensile Strength GN/m^2	Flexural Modulus E GN/m^2	Specific Modulus E GN/m^2
Spruce pulp fibre	0.60	0.98-1.77	1.63-2.95	10-80	17-133
Sisal	1.20	0.08-0.50	0.07-0.42	3-98	3-82
Flax	1.20	2.00	1.60	85	71
E Glass	2.60	3.50	1.35	72	28
Kevlar 49	1.44	3.90	2.71	131	91
Carbon	1.75	3.00	1.71	235	134

Due to their complex structure, the natural fibres are basically composite materials already. This structure is the reason why the flax fibre's mechanical properties are such that it is sometimes compared to an aramid fibre.

This section reviews those fibres considered likely to be used in composites in Western Europe.

B. STRAW

Straw is a by-product of cereal production. It is used for animal bedding and fodder but is largely wasted. Straw can be disposed of by burning or ploughing; the first option releases a large amount of smoke and is gradually being banned as it pollutes the environment, generates carbon dioxide, etc. The second option is not regarded by farmers as a true solution since straw encourages pests in the ground which endanger future crops, it is also a fuel consuming solution. It is likely that at least between a third and a half of the straw produced is treated by the growers as an unusable waste. Figures for straw production are not published but taking Western Europe major straw producing cereals - wheat, barley, oats - total estimated tonnage is in excess of one hundred million metric tons. Today, in percentage terms, the non-agricultural industrial uses of straw amount to less than two or three percent of that production.

Very recently, a paper manufacturing process has been successfully adapted, by the Agricultural Development Department of British Sugar plc to use straw on a commercial basis. The paper mill to be built on Humberside will produce 120 thousand metric tons per year of straw-based paper.

Straw has been commonly used as a building material in a clay/straw mixture mortar for centuries. Straw-based composites and clay for load bearing structures are not widely used in Europe. The lack of industrial process and building know-how has confined this type of product to limited housing programmes such as the Terre Paille project near Lyon.

There are no longer any manufacturers of straw cement slabs, they have mainly switched to wood wool cement slabs. However, even this market has begun to decline as insulation standards have increased and plastic foam is used instead.

Strawboards can be considered as composites since the panels are glued during the strawboard manufacturing process. Being tightly compressed, strawboards offer fire resistance, sound reduction and temperature insulation.

The main application of straw-based composites is found in external wall panels, partitions, roof decking, wall lining, flooring and ceilings.

The most well-known process is the Stramit straw conversion process. The strawboard manufacturing technique was invented in Sweden and developed in England more than forty years ago. In Western Europe the production capacity is about 30 thousand metric tons; Stramit Industries Ltd, UK, is the main manufacturer. Demand in Europe is not expected to increase dramatically, in spite of its low cost.

The product still faces user acceptance: they have to be convinced that highly compressed straw is extremely resistant to fire and the board has good structural properties and moisture resistance.

The construction industry prefers traditional materials such as: cement and steel - and building boards made from plywood, chipboard and blockboard. The potential development of strawboards is likely to take place in parts of the world where the concern about shortage of materials and energy is high and building standards are lower than in Europe.

C. JUTE

Jute is mainly used for sacking and carpet backing. No mention of any application in the composite business could be found in Western Europe, however it is used in the Far East. Exports of producing countries account for 2.4 million bales but the main markets for jute are the producers' domestic market, namely Bangladesh, India, China, Thailand.

Jute fibres and polyester resin have been used for the manufacture of low cost housing in India and Bangladesh. Initiated by CARE Inc of USA in 1972 and developed later as the UNIDO/Winfield/Madras house project, the programme supplied hundreds of houses. Since jute fibres alone do not provide enough strength and tend to absorb too much resin material, a mineral filler had to be added as well as a glass veil on the outer surface.

More recent studies have indicated that natural fibres and glass fibres in a hybrid type of laminate would give better results. These studies were carried out by H Wells, D H Bowen and I Macphail of the Atomic Energy Research Establishment England together with P K Pal of the Indian Jute Industries Research Association. A similar study was conducted by D S Varma, M Varma and I K Varma of the Indian Institute of Technology, in Dehli, with coir fibres instead of jute fibres. The fibres are treated with chemicals before the impregnation process can take place. This treatment, a surface modification, decreases the moisture absorption, increases the interfacial bond, enhances the wettability and is probably necessary for all natural fibres including miscanthus fibres. Studies conducted by K G Satyanarayana et al at the Regional Research Laboratory, Kerala, India showed that a copper coating obtained by activating the fibre surface with NaOH-HCHO/ammoniacal silver nitrate solution resulted in considerable increases in tensile and flexible strength of polyester-fibre composites fabricated from NaOH treated fibres. These methods as well as others based on polyurethane coating have never been fully commercialised.

More recent work was done in 1987 by R.N. Mukherjea et al at the Jadavpur University, Calcutta, India on the effect of polyesteramide polyol as interfacial agent in polyester-jute composites. The results indicated an overall improvement in flexural strength.

D. COTTON

The cotton fibre is a true cellulose fibre since it is not extracted from the plant stem but is in fact hair from the plant seed.

Cotton fibres are abundant in Europe in the sense that waste from the textile industry is quite readily available and constitutes a raw material feedstock by itself.

Fabrics which are not suitable for further processing into textile end products can be used as cotton flock and transformed into laminated composites or be chopped down to fibres and incorporated in Bulk Moulding Compounds (BMC) or in pellets. Fabrics purposely made range from fine weave to coarse with area weight between 130 and 200 g/m^2.

The cotton based reinforced composite market is divided into two main sub-markets:

- cotton laminates (sheets and blocks, tubes and rods)
- cotton filled compounds (pellets and BMC).

Cotton Laminates

The cotton laminated sheets come under various thickness. These sheets are machined in order to make parts which can be readily used by the specifiers. Most of the companies offering laminates also provide the machining service. Machining is time consuming and therefore the price of the finished items is quite high in comparison to injection moulded items.

Phenolic resins as well as epoxide resins are preferred, they offer the best performance for the manufacture of mechanically strong heat and wear resistant laminates used for machine tool guides, ships stern tube glands and bearings, yacht pulleys, circuit board supports, linings for sliding surfaces. The standard properties for cotton reinforced laminates are shown in Table IV.D.1 and for tubes is shown in Table IV.D.2.

The number of companies offering laminates is small. The following companies are recognised as leaders:

- o Isola Werke, Dueren, FRG
- o Tufnol Ltd, Perry Barr, UK
- o Permali Composites, Maxeville, France
- o Tenmat Ltd, Manchester, UK

The demand in Western Europe is estimated to be about one thousand metric tons of composite (i.e. 500 metric tons cotton) in 1990. It is not expected that the demand will rise over the 1990-2000 period due to competition from thermoplastic engineering plastics.

Moulding Compounds

The moulding compounds are mainly produced by the wet impregnation method. Various processes can transform the moulding compounds into shaped parts:

- o compression moulding
- o transfer moulding
- o injection moulding

Different kinds of resins may be selected. The main feature of moulded parts containing cotton fibres is the high impact strength.

In round figures the use of thermosetting resins from which moulding compounds are made is approximately 200 000 metric tons in Western Europe. Cotton filled moulding compound only accounts for about 10 thousand metric tons of this (i.e. about 3 500 metric tons of cotton).

The main Thermosetting Resins are:

- o Urea Formaldehyde (UF)
- o Melamine Formaldehyde (MF)
- o Phenol Formaldehyde (DAP)
- o Diallyl Phthalate (DAP)
- o Diallyl Isophthalate (DAIP)
- o Epoxides (EP)
- o Unsaturated Polyesters (UP)

The resins are supplied by companies such as Perstorp, Orkem, DSM, Ciba Geigy, BP Chemicals, Huels, Vynckier etc. for which the cotton filled moulding compounds activity usually represents a very small part of their resin business.

The mineral fillers are the main reinforcing materials, glass fibres are being specified more often as they improve the mechanical properties of the resins most effectively. Natural fillers such as wood flour and natural fibres represent a small percentage of the thermoset moulding materials market and are often not suitable as they are subject to microbiological attack. One application where natural fibres may make progress is in canoe manufacture where flax, unsaturated polyester resin composites can be used to make a structure that is as stiff as GRP, and inherently buoyant.

TABLE IV.D.1
STANDARDS FOR INDUSTRIAL LAMINATED THERMOSETTING SHEETS
COTTON FABRIC REINFORCEMENT

Standards	FRG	DIN 7735	Hgw 2082	Hgw 2082.5	Hgw 2083
	France	NF			CC
	UK	BS	F2, F3		F2
	USA	NEMA-LI1	C	L	
	International		PF CC 1	PF CC 2	PF CC 3

Flexural strength d<10 mm	N/mm^2 min.	130	115	150
Impact strength a_{k10}	kJ/m^2 min.	30	20	35
Impact strength, notched	kJ/m^2 min.	10	10	12
Tensile strength	N/mm^2 min.	80	60	100
Compression strength	N/mm^2 min.	170	150	170
Fission force	N min.	2500	2500	2500
Modules of elasticity	N/mm^2	$7\ 10^3$	$7\ 10^3$	$7\ 10^3$
Resistance between plugs	min.		10^7	
Breakdown voltage, ||, 90±2°C				
1 min, d=25 mm	kV min.	8	20	8
Breakdown voltage, 90±2°C				
1 min, d=3 mm	kV	5	5	5
Tracking resistance	grade	KC100	KC100	KC100
Glow Resistance	grade	2b	2b	2b
Thermal Conductivity	W/m K	0.2	0.2	0.2
Coefficient of thermal				
expansion	10^{-6}	20-40	20-40	20-40
Limiting temperature	°C	110	110	110

TABLE IV.D.2

MINIMUM MECHANICAL AND ELECTRICAL PROPERTIES OF TUBES

COTTON FABRIC REINFORCEMENT

Standards	FRG	DIN 7735	Hgw 2085	Hgw 2086	Hgw 2088
	USA	NEMA-LI1	C	L	
Specific gravity		g/cm^3	1.15-1.4	1.15-1.4	1.2-1.4
Flexural strength		N/mm^2 min.	80	80	80
Tensile strength		N/mm^2 min.	50	50	
Compression strength		N/mm^2 min.	40	40	70
Modules of elasticity		N/mm^2	$0.6\ 10^4$	$0.6\ 10^4$	$0.6\ 10^5$
Resistance between plugs					10^5
Breakdown voltage, $\|\|$, 90±2°C					
1 min, d=25 mm		kV	10	10	5
Breakdown voltage, $\perp$ 90±2°C					
1 min, d=3 mm		kV	5	5	5
Tracking resistance		grade	KC100	KC100	KC100
Limiting temperature		°C	120	120	120

E. HEMP

It has not been possible to find out if any branch of the composite industry is using hemp fibres.

The known applications are to be found in the rope sector, in the textile industry and the paper industry.

F. FLAX

In the EEC, flax was grown on 75 000 hectares in 1988. This yields about 33 000 metric tons of flax yarn for textiles. Flax fibre is harvested in France, Benelux (mainly Belgium), UK (mainly Ireland) and Germany. France is the main producer of raw flax with 55 000 hectares. The prime application for the flax fibres is high quality, rather expensive textile products. The EEC textile trade balance with other parts of the world shows an overall large deficit except for flax. Special paper products such as cigarette paper are made from flax fibres. Two other types of application are related to composites; flax based fibre boards and fibre cement boards.

Flax fibre based boards

These boards are made from flax residues shives (which represent about 50 percent of total flax production)in France and Belgium. They can be either from flax residues only or from flax residue and wood chips, wood fibres, etc.

The production of flax fibre based boards is expected to increase in the coming years. The raw material supply, which up to now has balanced the demand of 90 000 metric tons, might not be sufficient to feed the production plants and thus an opportunity for extra production of flax shives will arise.

Flax in fibre cement boards

As an alternative material to asbestos, vegetable fibres are of interest to companies which anticipate a total ban on asbestos. The asbestos fibres were not only a cheap reinforcement material but give the right consistency and viscosity to the cement as it is processed. Very little (perhaps 100 metric tons) of flax is being used in fibre cement boards by Eternit.

Flat fibre cement boards can be manufactured, but the main application of the moment is focused on the corrugated board.

G. OTHER FIBRES

Coir, sisal, banana and pineapple leaf fibres form large renewable resources in many developing countries which do not have indigenous suppliers of glass or asbestos fibres. Their behaviour as fibre-resin composites have been studied by K G Satyanarayana et al, R N Mukherjea et al and various other authors. Although consumer products such as wash basis, chair sears, crash helmets have been developed, no industrial fabrication process has been reported.

Theses fibres are imported into Europe for purposes other than composite fabrication. Sisal is the only material which was, as far as we are aware, being tested for fibre cement product fabrication (by Eternit).

H. FIBRE BOARDS

Fibre boards should not be confused with particle boards as it is often the case. Furthermore, two different processes are used to manufacture the boards; only one of them, known as the "dry process", uses resins as binding agents.

The so-called Medium Density Fibre boards (MDF) can be considered as true composites.

The binding resins are thermoset resins; phenol formaldehyde, urea formaldehyde, melamine formaldehyde or resorcinol formaldehyde.

The fibres used are mainly wood fibres, but even though this type of fibre represents the major part of the world production, in Europe flax residues, (shives), represent a small but still reasonable percentage of the production. In Western Europe, more than half a dozen companies are making fibre boards almost exclusively out of flax residues.

It is worth mentioning other types of matrices, cement and gypsum.

These boards are homogeneous sheets, pale sand in colour, 3 to 60 mm thick, with usually smooth sides. Their densities lie in the range 640-860 kg/m^3, a typical board density being 730 kg/m^3. Strength properties are given in Table IV.H.1.

Fibre boards are used in the furniture industry as well as in the construction industry. According to the type of binder, the boards can sometimes be used for outdoor applications.

The market for such boards in Western Europe is about 850 000 m^3 as shown in Table IV.H.2 and growing quite rapidly. Capacities are being added to meet the market demand. Installed capacities will be 2.5 million m^3 by the end of 1990 and 3.4 million m^3 by the end of 1992.

Currently flax residue based board represent about 10 percent of this output i.e. 90 000 metric tons. Manufacturers known to be active in this area are shown in Table IV.H.3.

TABLE IV.H.1

MEDIUM DENSITY FIBRE BOARD PROPERTIES

	Thickness mm	Range of Values N/mm^2	BS 1142 Value N/mm^2
Tranverse Internal Bond	12-19	0.6-1.5	0.6
Modulus of Elasticity	15-19	2100-4000	2500
	22-30	Max. 3500	2500

TABLE IV.H.2

MDF DEMAND IN WESTERN EUROPE, 1988

(thousand cubic metres)

Italy	240
Spain	140
FRG	90
UK*	150
Benelux	57
France	40
Others	133
Total	**850**

* includes Ireland demand figure

TABLE IV.H.3
FLAX-BASED FIBRE BOARD

Companies known to be active in this area are:

Linex - Koewacht

Flaxipan N.V., Hooglede, Belgium

Interlin N.V., Waregem, Belgium

Linopan N.V., Wielsbeke, Belgium

Menotex N.V., Menen, Belgium

Placolin N.V., Hooglede, Belgium

Unilin N.V., Wielsbeke, Belgium

La Liniere, Trie Chateau, France

Linex Panneaux, Ste Marie des Champs, France

De Sutter, Seine Maritime, France

I. SUMMARY OF PROPERTIES

The key properties of some natural fibres with glass as comparison, are shown in Table IV.I.1.

TABLE IV.I.1
PHYSICAL PROPERTIES OF SOME NATURAL FIBRES

	Density g/cm^3	UTS MN/m^2	T Modulus GN/m^2	Percentage Elongation to break
Jute	1.45	533	2.5-13.0	1-2
Coir	1.15	131-175	4-6	15-40
Sisal	1.45	586-640	9.4-15.8	2.8-7
Pineapple leaf	1.44	413-1 627	39.5-82.5	0.8-1.6
Palmyra	1.092	95-220	3.3-7.0	3.2-11.2
Banana	1.35	529-754	7.7-20.8	1.8-3.5
Glass	2.54	827-1 724	68-96	2.4-5

V END USE MARKETS

A. INTRODUCTION

Residues of annual plants grown for other purposes are a source of low price raw material for fibrous fillers. They are the most important substitute for wood in fibre boards. The flax residues are far ahead of other residues such as straw as far as true composite products are concerned in European countries. In other parts of the world, bagasse, the residue of sugar cane, which has a constitution similar to that of wood, accounts for a large part of non-wood, non-flax fibre boards.

The substitution of wood by annual plants has two main drawbacks:

- o tensile and flexural strengths are reduced
- o storage and, to a lesser extent, collection and transport are expensive

but there are also advantages:

- o low cost material
- o favoured by environmental agencies.

The end use markets likely to use natural fibre composites are discussed below.

B. ELECTRICAL/ELECTRONIC

o Audio/Video

Large market areas such as TV back panels which used to be fibre board (wet felt type process - not really considered as composite) are no longer an end use for natural fibre composites as the industry has switched to injection moulded thermoplastics for better appearance. Loudspeaker cases can be considered as furniture and are discussed later.

o Electrical Appliances

Natural fibres have largely been replaced by glass fibres. In many cases this happened because the matrix itself, a thermoset resin, had been displaced by a better performing material (ABS, thermoplastic) and so a 'hot' process was used and the moisture content in natural fibres makes them unsuitable for use in such circumstances.

C. TRANSPORTATION

Sound insulating fibre mats made of cotton are still used in some passenger cars. For a long time the automotive industry was a good customer but new products have replaced these textile fibre mats on grounds of cost, performance or fire regulations and new specifications.

Wood flour as filler in a polypropylene matrix has found a niche in the automotive industry. The rear panel shaft and door lining panels are typical applications. Considered as a thermoplastic compound rather than composite, it is probably the only industrial application of its kind. However, quantities are still limited: in the range of 5 000 metric tons (wood flour only) with the Solvay subsidiary Gor being the main producer in Italy. The present trend is to switch from filled polypropylene compound to rigid polyurethane.

D. BUILDING AND CONSTRUCTION

The main applications are: partition walls and panels, insulation slabs, roofing slabs and sheets.

The reinforcement material is mainly wood wool followed by straw. This market is very cost sensitive and the market share of wood wool based products is not expanding.

Straw panels can scarcely be considered as composite panels since straw, subjected to reasonably high temperature and pressure, releases its own internal resinous substances which act as binder materials. Glue is only added to bond the surfaces with a paper liner.

The replacement of asbestos in construction products opens the door to natural fibres: asbestos free corrugated and flat fibre cement sheets are now manufactured on a regular base. The following fibres have been tested: flax, sisal fibres but also man made fibres such as PP and synthetic textile fibres. Plain flat cement fibre sheets filled with wood fibre and particles are also proposed by Pyrok Building Products Ltd. Due to the alkalinity of the cement, which stops fibre decay, the sheets show excellent stability in the presence of water.

Recently gypsum has been used to manufacture fibre boards, eastern countries are the main producers of such boards which are mainly used for interior finish construction. The technology was provided by the German (FRG) company, Siempelkamp, Krefeld.

Natural fibres embedded in concrete can provide some improvement in the properties of the concrete. These improved properties are:

- o increased flexural strength
- o post-crack load bearing capacity
- o increased impact toughness
- o increased viscosity in the fresh state

On the other hand, natural fibres show low elastic modulus, high water absorption, susceptibility to fungal and insect attack, and variability of properties amongst fibres of the same type. They are not recommended for load-bearing structures where a decrease in toughness with time could prove dangerous and so natural fibres have not been able to compete with man-made fibres. A number of man-made fibres are already used such as glass fibres (treated glass to withstand the alkalinity of the concrete), metal needles, polypropylene fibres, and of course asbestos.

E. FURNITURE

The furniture business is probably the main market for natural fibre reinforced composites: the product is the MDF board which is described in the Fibre board section.

MDF is particularly used for cabinet and desk carcasses, drawers, door frames, unit tops, mirror and picture frames. Loudspeaker cases made from MDF boards show better sound dampening characteristics than others made from hardboard.

Decorative surfacing materials are usually used to line the boards. Such linings and coating offer high quality finish to the furniture industry and related activities such as: shopfitting, kitchen and bathroom units, caravan and mobile home interiors.

F. CONSUMER PRODUCTS

Straw boards and fibre boards are used to manufacture pallets and crates, i.e. packaging items.

Moulded items such as knobs, handles of household appliances and housewares have a niche in this sector.

G. MEDICAL PRODUCTS

Natural fibres could certainly be used in new applications in this sector but since it can be considered as a high technology sector, the potential users, the hospitals and clinics, are looking for high performance materials, either resin or fibre and no use of natural fibres in composites has been detected. One of the key problems is thought to be the effect of sterilisation (either by steam or radiation) on fibre properties and the bonding to the matrix.

H. INDUSTRIAL PRODUCTS

Cotton reinforced laminates have a niche in this market which is mainly using man-made fibres and mineral fillers. The size of this natural fibre composite market is of the order of one thousand metric tons in Western Europe.

Gear wheels, bushes, bearings for highly demanding applications and all sorts of items for applications where wear and high impact strength is a problem can be machined out of cotton laminates.

Phenolic cotton materials are the work horse grades for mechanical applications but cannot operate at a high temperature. Epoxy cotton grades have excellent electrical properties, are resistant to surface tracking and replace phenolics in demanding applications such as military fittings.

I. SUMMARY

The furniture and the building and construction industries are at the moment the main market segments for natural fibre composite products such as the Medium Density fibre board and asbestos-free fibre cement products.

The already well established MDF products will show a rapid growth in both market segments. Wood fibres, dominate the range of MDF products, but other fibres could obtain a small share of these segments. Flax-based fibre boards have demonstrated that flax residues could be as competitive as wood fibre-based boards.

Asbestos-free fibre cement boards, either corrugated or flat, are still in infancy but a major increase is forecast as the ban on asbestos in building products becomes effective.

VI PROSPECTS FOR NATURAL FIBRE COMPOSITES

A. INTRODUCTION

Potential applications for an inexpensive fibrous material available in large quantities are certainly straw boards and fibre boards. Straw boards can be made without any prior treatment; fibre boards can be made after thermomechanically or chemically treating the stems or leaves to extract bundles of fibres. Any new fibre such as Miscanthus could be used in this application.

High technology applications require a special treatment of the fibres to render them either hydrophobic or fire resistant, etc. Research is being conducted in Europe (Bangor) and in Canada to improve the surface properties of natural fibres. However the price of the fibre would then be set at higher levels and the quantities involved would not be large.

B. SCIENTIFIC STATUS AND TECHNICAL DEVELOPMENT

Research is being conducted in various parts of the world through national laboratories, university wood and forestry departments, independent research institutes. They all aim at improving the fibres, making them resistant to weakening and degrading phenomena.

In the USA and in Europe, the focus is mainly set on wood fibres but Asian countries concentrate on their domestically grown fibres.

Technical development is also being conducted by independent research institutes or university departments getting contracts and funds from industrial companies as well as state development agencies.

Among other topics being worked on are:

- o chemical modification of plant fibre
- o alkaline pretreatments in fabric finishing
- o new process to recover undamaged, clean elementary fibres
- o improvement of the bond between fibre and matrix.

There seems to be no global or even continental co-ordination of research even though groups of three or four research centres exist.

Research and development on natural fibre composites can be carried out by institutes such as:

- o LIRA, Lambeg Industrial Research Association
  Lambeg, Lisburn, Co. Antrim, Northern Ireland
- o British Textile Technology Group
  Didsbury, Manchester, UK
- o TNO
  Delft, the Netherlands
- o The Biocomposites Centre - University of Wales
  Bangor, Gwynedd UK

The following universities and research organisations are currently studying natural fibre structure and properties:

- o The Biocomposites Centre - University of Wales
  Bangor, Gwynedd UK (see Appendix for details)
- o Agricultural University - Department of Forest Technique
  Wageningen, the Netherlands
- o ITF - Institut Textile de France
  Ecully, France (see Appendix for details)
- o Stazione Sperimentale Per La Celulosa Carta e Fibre Tessili Vegetali et Artificiali
  Milan, Italy

In the field of pulp and paper, there are many research organisations which are involved in applied research; the work done on fibre boards is regarded as one of the research activities covered by this sector of the industry.

Except for the University of Wageningen, no other research body is carrying out either fundamental or applied work with miscanthus plant fibre.

The industrial R&D laboratories of companies such as Eternit, Berlin and Leimen, FRG, also have strong interest in natural fibres.

C. PROBLEMS HINDERING THE INTRODUCTION OF NATURAL FIBRES IN COMPOSITES

The research work conducted on natural fibres has mainly focused on solving problems linked with the transformation of fibres into textile products; upholstery, clothing, etc. Natural fibres are not considered as a true reinforcing material for various reasons.

Natural fibres do not get the technical and marketing support that companies provide to improve the market penetration for their synthetic products. The most obvious examples are the development of glass and synthetic organic fibres by the multinational companies such as Owens Corning and Du Pont.

Natural fibres do not provide the manufacturer of composite products with the consistency that glass fibre offers. The ease of processing is a vital point when productivity is concerned. The broad band of grade specification of natural fibres is likely to inhibit further growth as final product specifications become more stringent.

Biodegradability and poor bonding are minor problems which can certainly be overcome by chemical or physical treatments which are, however, not fully developed at present. The fact that natural materials support microbiological growth has certainly been a drawback in the past; appropriate chemical treatments could overcome this.

D. COMPETITION

Fibres which are not grown in Europe are not competing with European grown fibres. Jute production is so erratic in terms of quantity that no producer willing to import jute fibre, could rely on a constant supply. Coir production is affected by the political situation in Sri Lanka. Sisal has seen its production levels decrease due to the worsening economic situation in Tanzania.

The bagasse based fibre boards do not represent, at the moment, a threat to wood fibre and flax residue based fibre boards since production is mainly aimed at domestic markets and the freight costs are too high to justify export to Western Europe.

The land surface covered by flax is steadily increasing, encouraged by funding from the EC. The residues from linen production find uses as animal bedding, compost and flax shrive based fuel and, as mentioned previously, in fibre boards. It should be noted that flax fibres account for only 2 percent of the total consumption of fibre in the world; the by-products and residues supply for composite products manufacturers is not large and competition with other materials is marginal.

E. CONCLUSIONS

There is basically no use of natural fibres in composites of high technical specification. Where natural fibres are used the main fibre is wood based or flax residue. Straw is used as a cheap insulating material but its growth prospects are poor, in spite of the environmentalists efforts to encourage its use. We found no use of miscanthus fibre in composites, all the research work is being done on the basis that miscanthus is a good fibre for pulp for paper.

The basic problems confronting the user of natural fibres in composites are:

- o Lack of uniformity from crop to crop
- o moisture content
- o lack of adhesion to matrix
- o bio degradability.

All these problems can be solved by chemical treatement of the fibres, but they add to the cost and reduce the incentive to switch from synthetic fibres such as glass, carbon fibre and polypropylene.

Table VI.E.1 summarises the estimated usage of natural fibres in composites in Western Europe in 1989 with comments on likely future trends. The estimated total of 669 600 metric tons compares with 422 000 metric tons for glass fibre in composites. However, this comparison is not really significant as the end uses are not the same. The use of natural fibres in composites is dominated by straw, flax residue and wood fibre in low specification building products. Whereas glass fibre is used in higher specification industrial and consumer products.

TABLE VI.E.1
SUMMARY OF NATURAL FIBRE USAGE IN COMPOSITES IN WESTERN EUROPE 1989
(metric tons)

Fibre	Product	Tonnage Fibre	Tonnage Composites	Comments
Straw	Stramit	30 000	30 000	slow growth.
Jute	-	nil	-	some in India.
Cotton	Laminates	500	1 000	no growth.
Cotton	Moulding Compounds	3 500	10 000	low growth.
Hemp	-	nil	-	only in textiles.
Flax	Fibre Board	-	90 000	steady growth.
Flax	Fibre Cement	100	500	Eternit doing trials.
Wood	Medium Density Fibre	620 000	680 500	growing rapidly.
Total		**654 100**	**811 500**	

If the key objective of this project is to find uses for miscanthus fibre in composites the conclusions are:

1) It has to compete with flax residues and wood fibre.

2) The market for high added value products is very small and probably not worth the research effort to make the fibre chemically receptive to bonding.

APPENDIX I
FIBRE PRODUCTION STATISTICS

TABLE A.I.1
COTTON PRODUCTION (FIBRE CROPS)
(thousand metric tons)

	1984	1985	1986
Africa			
Egypt	1 100	1 200	1 250
Sudan	640	590	440
Ivory Coast	142	216	206
Zimbabwe	250	298	203
Mali	188	186	195
Burkina Faro	80	100	142
Benin	88	86	139
Others	1 088	1 136	1 170
Total	**3 576**	**3 812**	**3 745**
America			
USA	7 498	7 713	5 629
Brazil	2 160	2 840	2 314
Mexico	828	576	420
Paraquay	320	485	375
Argentina	610	536	340
Colombia	380	340	300
Peru	280	280	270
Others	558	583	464
Total	**12 634**	**13 353**	**10 112**
Asia			
China	18 774	12 441	10 620
India	4 338	4 392	4 288
Pakistan	3 026	3 651	3 720
Turkey	1 508	1 347	1 235
Syria	451	487	419
Others	939	1 035	912
Total	**29 036**	**23 353**	**21 194**
Europe	629	757	822
Oceania	400	679	617
USSR	8 619	8 750	8 230
GRAND TOTAL	**54 894**	**50 704**	**44 720**

Source: FAO Production Yearbook

TABLE A.I.2
JUTE AND JUTE-LIKE PRODUCTION (FIBRE CROPS)
(thousand metric tons)

	1984	1985	1986
Asia			
India	1 402	2 291	1 400
Bangladesh	929	1 557	907
China	745	2 060	715
Thailand	171	266	240
Total*	**3 406**	**6 360**	**3 477**
Africa	21	21	22
America	113	101	101
USSR	58	60	63

* Total amount includes all jute and jute-like production in Asia.

Sources: FAO Production Yearbook

TABLE A.I.3.

COIR FIBRE EXPORTS*

(metric tons)

(thousand metric tons)

	1986	1987	1988
Sri Lanka	85 656	76 726	67 195
Thailand	6 183	6 551	

* Includes mattress fibre, bristle fibre, twisted fibre, coir yarn, coir twine.

TABLE A.I.4

SRI LANKA EXPORTS OF TWISTED FIBRE, COIR YARN, COIR TWINE TO THE EEC, 1988

(metric tons)

	Twisted Fibre	Coir Yarn	Coir Twine
Belgium	1 705	-	-
Denmark	-	24	-
France	-	-	-
Greece	10	-	-
The Netherlands	2 001	59	12
Ireland	-	-	6
Italy	179	161	-
Portugal	-	24	-
Spain	417	-	-
UK	470	18	722
FRG	8 865	-	10

Source: Sri Lanka Coconut Development Authority Annual Review for 1988
Thailand, Office of Agricultural Economics

TABLE A.I.5

ANNUAL GLOBAL PRODUCTION OF MISCELLANEOUS FIBRES

(thousand metric tons)

Coir (Cocos Nucifera)	300
Banana	100
Sisal (Agave Sisalana)	600
Jute (Corchorus Capsularis)	4 000

Note:

There are fluctuations from year to year due to weather conditions affecting crop yields.

APPENDIX II

ASSOCIATIONS AND RESEARCH INSTITUTES CONTACTED DURING THE COURSE OF THE STUDY

Companies/Institutes contacted regarding natural fibre composites. Listing excludes contacts that subsequently were found not to be involved in natural fibre composites.

1. Tufnol Ltd.
   PO Box 376
   Wellhead Lane
   Perry Barr
   Birmingham B42 2TP

   Tel: 021-356 9351
   Fax: 021-331 4235

   Cotton reinforced laminates using phenolic or epoxy resins.

2. La Liniere
   F. 60590 Trie Chateau
   France

   Tel: 010 33 44 49 74 22

   Flax/straw/wood particle boards using urea formaldehyde as binder.

3. DSM Resins UK Ltd (Ex Freeman Chemicals Ltd)
   PO box 8
   5 Civic Way
   Ellesmere Port
   South Wirral L65 0HB

   Tel: 051 355 61 70
   Fax: 051 357 12 82

   Considered jute based DMC but gave up due to water absorption problems.

4. Permali Composites
   8 Rue Andre Fruchard BP12
   F 54320 Maxeville

   Tel: 010-33 83 35 4410
   Fax: 010-33 83 32 23 18

   Cotton reinforced laminates represent 8 percent of sales.

5. PIM Board Co Ltd
   Hanworth Road
   Sunbury on Thames TW 16

   Tel: 0932 7855123

   Make building boards out of waste paper by wet process, chemicals help bind the fibres.

6. Torvale Building Products Ltd
   Pembridge
   Leominster HR6 9LA

   Tel: 05447262

   Manufacture wood wool/cement slabs.

7. Tenmat Ltd (division of T&N PLC)
   Bowdon House
   Ashburton Road West
   Trafford Park
   Manchester M17 1RU

   Tel: 061-672 2181
   Fax: 061-872 7596

   Manufacture asbestos free composites with organic fibres.

8. Chavanoz Industries
BP 56
F 38230 Pont de Cheruy

Tel: 010-33 78 32 44 44

Developing PVC covered Flax yarns for geotextiles.

9. Marley Waterproofing Ltd
6 Pembroke Road
Sevenoaks TN13 1XR

Tel: 0732 451033
Fax: 0732 740154

Used to make wood wool/cement roofing slabs.

10. Stramit Industries Ltd
Yaxley Eye IP23 8BW

Tel: 037 983 465
Fax: 0379 836659

Manufacture about 30 000 metric tons per year of straw based building board.

11. Vynckier NV
Vyncolite Division
Neuwevaart 51
B-9000 Gent

Tel: 010-32 91 255 741
Fax: 010-32 91 241 209

Manufacture cotton filled composites, also coconut shell flour was used in the past.

12. Norsolor (Orkem)
Tour Aurore
Place des Reflets Cedex 5
F 92080 Paris, Defense 2

Tel: 010-33 147 78 51 51
Fax: 010-33 147 78 57 57

Supply resin to MDF manufacturers and know the flax and straw board makers.

13. Agricultural University
Department of Forest Technique
General Foultesweg 64
NL 6703 EG WAGENINGEN

Tel: 010-31 83 70 89 111

Doing work with miscanthus fibre to make pulp for paper, not involved in composites.

14. Fibre Building Board Organisation (FIDOR)
1 Hanworth Road
Feltham, Middlesex TW13 5AF

Tel: 01-751 6107

Represents importers of building boards made from wood fibres.

15. Centre For Agricultural and Biological Research
PO Box 14
6700 AA Wageningen
Netherlands

Tel: 010 31 83 70 19 012

Growing miscanthus for trials but say it is not a good break crop, they think miscanthus could be a good paper fibre.

16. Eternit
Rue de l'Amandier BP2
F78540 Vernouillet, France

Tel: 010 33 139 79 60 60
Fax: 010 33 139 65 68 12

Making small tonnage of flax and sisal reinforced cement corrugated boards.

17. Association Technique pour la Production
et l'Utilisation du Lin (ATPUL)
Rte de St Pathus
F 60 Lagny le Sec, France

Tel: 010 33 44 60 50 37
Fax: 010 33 44 21 09 02

Research association, knowledgable on uses for flax.

18. Fibre Cement Manufacturers Association Ltd
PO Box 92 Elmswell
Bury St Edmunds
Suffolk IP30 9HS

Tel: 0259-379
Fax: 03598-385

Group of 4 companies promoting use of fibre reinforced cement products not containing asbestos.

19. Lambeg Industrial Research Association (LIRA)
Lisburn Co Antrim
N. Ireland BT 27 4RJ

Tel: 0846 66 22 55
Fax: 0846 66 16 91

Working on research project using pineapple leaf fibre, have developed PP fibre reinforced cement.

20. The Bio Composites Centre
University of Wales
Bangor
Gwynedd LL 57 2UW

Tel: 0248 370 588
Fax: 0248-370594

Doing significant research on natural fibres, see Appendix.

21. Indian Jute Industries Research Association
17 Taratolla Road
Calcutta 700 088
India

Tel: 777 145

Are involved in new uses for jute.

22. Centre Scientifique et Technique du Bâtiment
4 avenue du Recteur Poincarré
75016 Paris
France

Tel: 010 33 1 40 50 28 32

Are specialists of the building industry. Do not recommend the use of natural fibre in concrete in Europe.

23. Centre Technique de l'Industrie des Papiers, Cartons et Cellulose
Domaine Universitaire
St Martin d'Heres
France

Tel: 010 33 76 44 82 36

The Centre is conducting advanced research on wood mainly but also flax fibre pulp.

24. Stazione Sperimentale per la Celulosa Carta et Fibre Tessili Vegitali ed Artificiali
Piazza Leonardo da Vinci
Milano
Italy

Are cooperating for some projects with ITF, LIRA and ATPUL.

25. British Textile Technology Group,
Didsbury
Manchester M20 8R

Tel: 061 4458 141
Fax: 061 434 99 57

Have not done any experiments on natural fibre composites but have the potential for evaluating them.

26. British Cement Association
Wexham Springs
Slough SL3 6PL

Tel: 0753 662727

Have expertise in fibre reinforced composites and, as in part a contract research organisation, offer research services.

THE BIOCOMPOSITES CENTRE

at the

UNIVERSITY OF WALES,

BANGOR

Introduction

The Biocomposites Centre has been established at the University College of North Wales, Bangor, by the Welsh Development Agency in association with the School of Agricultural and Forest Sciences. The Centre has also attracted significant funding from the public and private sectors in the form of grants, sponsorship, and research contracts.

Background

The techniques presently used in the manufacture of composites from plant fibres can be improved in three main ways:

- a broader range of plant fibres might be used. The most common source of fibre at present is wood. Much annual plant fibre is not used by industry. Many types of annual plant fibre are available at little more than transport cost. Others have properties which are potentially valuable (existence of long individual fibres, or fibre bundles; unusual cell wall structure and/or chemistry etc).

- the properties of existing products might be improved. This would involve the chemical modification of the fibre surface to make it more water resistant and easier to bond, and/or control of the physical environment in which interfibre bonds are made.

- high performance composites might be made through the combination of larger quantities of adhesive, or better adhesives, with chemically modified fibre. In existing wood-based composites very little adhesive is used, so that the normal definition of a composite as a material consisting of fibres embedded in a matrix is scarcely applicable. As can be seen from Table 1, plant fibre composites, of which wood is a natural example, are of low specific gravity compared to conventional fibre composite systems. Their strength and stiffness per unit weight exceeds that of glass fibre composites. Because the plant cell wall is itself a composite, the toughness (or work of fracture) of wood is of similar order to that of carbon fibre composites.

Table 1. Strength and stiffness of air dry spruce wood

Compared to glass fibre and carbon fibre reinforced plastics

Material	Sp. Gr.	Tensile strength (MN/m^2)	Specific Tensile (MN/m^2)	E (GN/m^2)	Specific E (GN/m^2)	Work of fracture (J/m^2)
Spruce wood	0.46	104	226	10	22	10^4
GRP	1.80	276	153	18	10	10^5
CFRP	1.50	1040	693	180	120	10^4

Source : J.M. Dinwoodie, 1975: J. Microsc. 104 (1) 3-32.

Bearing in mind that individual plant fibres are often as much as five times stronger than the values shown above for wood, it is clear that they have considerable unrealised potential for the manufacture of high performance composites. Two additional factors strengthen their position as competitors in glass and carbon fibre markets:

- the surface chemistry of plant fibre is such as to make it readily reactive to adhesives;

- plant fibre is a fraction of the cost of glass and carbon fibre. With uncertainty in the future supplies (and cost) of oil, fibres originating from a renewable resource are obviously attractive. Because some plant fibre resources are underutilised (e.g. cereal straws), while others are likely to be increased with the substitution of fibre crops for food crops, the long term availability of plant fibre at low cost seems ensured.

Current resources

The Biocomposites Centre has its roots in the Wood Science group in the School of Agricultural and Forest Sciences in the University at Bangor. The Wood Science Group is the only one of its kind in the U.K., being an interdisciplinary group consisting of chemists, physicists and biologists (5 academics and 10-15 postgraduates and postdoctoral research officers). The group has good laboratories, and access to first rate analytical facilities (Fourier Transform Infra Red, Solid State Nuclear Magnetic Resonance, Mass Spectroscopy, Scanning and Transmission Electron Microscopy with Energy Dispersive X-Ray Analysis etc). Their past research activities have been focussed on:

- the chemical modification of wood surfaces;

- the design of adhesive systems specifically for plant fibre systems;

- the characterisation and simulation of the physical environment inside products being manufactured.

The Group has a good publications record , one patent pending, and an international reputation: having collaborated with and advised the major research wood research centres in the U.S.A., Holland, New Zealand and Malaysia, they believe their own work to be as advanced at that anywhere else in the world.

Recent and Future Developments

The Biocomposites Centre was established early in 1989. It is an independent organisation but has links with the academic Wood Science Group so as to make optimum use of staff expertise and physical resources. By the end of 1989 the Centre will be employing 12 scientists and technicians. A further 8 will join its strength in the following year.

To facilitate the commercialisation of novel ideas for the processing and use of plant fibre which have been developed in the laboratory, the

Biocomposites Centre is now establishing a combination of pilot plant which will be unique in the world. This will include:

- first and second stage pressurised refiners with facilities for chemical modification of fibre over a range of temperatures and pressures not presently available in industry;
- blowline blending with additives;
- fibre drying using a range of drier conditions;
- production of air-formed "mattresses" or "webs" of fibres;
- prepressing of fibre products
- pressing of fibre products in a sealed environment simulating that existing in industrial conditions, with or without steam injection or RF heating.

It is anticipated that these facilties will be operational by early 1990. At a later date, equipment for injection moulding, extrusion etc is likely to be installed.

In addition the Centre is in the process of enhancing the analytical facilities available in Bangor, and adding to them the full range of equipment needed for polymer characterisation.

Summary of proposed research work

The research work which will be tackled falls into the following areas:

(a) chemical modification of plant fibre;
(b) design of improved formaldehyde based adhesives for wood based composites;
(c) development of adhesives systems for fibre bonding;
(d) reduction of strain reversal in composites exposed to water;
(e) improvement of the board pressing model and prediction of bond strength development;
(f) simulation of industrial pressing on laboratory presses;
(g) steam injection pressing;
(h) development of moulded products;
(i) developments in mechanical pulping technology.

These areas are discussed at some length in Appendix 1. They can be briefly summarised as follows:

Plant cell walls (ie fibre walls) contain abundant hydroxyl groups on polysaccharides and lignin. The bonding together of plant fibres with an adhesive largely involves the formation of primary and secondary valence bonds between such hydroxyl groups and the adhesive. However, these hydroxyls are also very water reactive. In the context of adhesive bond performance, this has at least three important implications:

- the fibre wall structure will swell in the presence of water. Because this swelling is anisotropic, swelling is likely to cause high shear stresses where the fibres bonded together are not perfectly aligned;

- the water may break secondary valence bonds between the fibre and the adhesive;

- in the presence of water, stress locked into the adherends can be released, so that strain introduced in them in order to get their surfaces close together (as in pressing operations) is reversed.

These facts are largely responsible for the poor penetration of plant fibre into the markets for structural composites.

Past research at Bangor has shown that these problems can profitably be tackled by

- chemically modifying the fibre hydroxyl to make it water resistant. The modification system can simultaneously be used to provide a strong primary valence bond between the cell wall polymers and an adhesive. This is the essence of areas (a), (b), and (c) above.

- careful control of the physical environment inside the composite during manufacture, to allow stress relaxation, and thereby to eliminate the forces responsible for much composite failure. This approach is important in areas (d), (e), (f) and (g) above.

Secondary benefits of chemical modification of fibre may be seen in other kinds of property modification. It may be possible to produce bio-resistant composites without using toxic materials. It seems likely that it will be possible to bond non-leachable hydrophobic fire retardant materials into the composite with the adhesive. The feasibility of making fibres compatible with molten thermoplastic adhesives has already been demonstrated. It is likely that it will also be possible to make fibres which show controlled absorbtion of water (for biomedical applications, thickeners, and consistency controllers) or of other solvents (for solvent purification, chromatography etc).

Work in a number of the above areas is in hand. Those wishing to discuss opportunities for such research should contact

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Appendix 1. Details of the proposed research work

(a) **Chemical modification of plant fibre.** Considerable effort has already been devoted in Bangor to the possibility of enhancing the properties of wood by chemical modification. The majority of the approaches used fall into one of three categories:

- esterification (mainly acetylation; e.g. Rowell, Tillman and Simonson, 1986);
- carbamo-esterification (urethane technology; e.g. West and Banks, 1986);
- etherification (reactions with alkyl halides or epoxides; e.g. Rowell, 1983).

In most cases, the modification of solid wood rather than fibre has been attempted, with consequent difficulties of accessibility. Also, many workers have offered systems which could never be viable industrially because of long reaction times. One of the more promising to date is the acetylation system of Rowell and co-workers. However, the fibre so produced is inherently difficult to bond with adhesives; it is also likely to be corrosive to metal fixtures if wetted.

Staff at Bangor have recently developed a fibre modification system based on a bi-functional isocyanate, which is easy to bond and does not have a corrosion risk associated with it (Banks and Earl, 1987). Moreover, through study of the reaction kinetics, it has proved possible to reduce the reaction times to levels acceptable industrially. Much further work is needed to establish

- whether the best isocyanate and catalyst systems have been used in the past work;
- whether etherification (or other) reactions based on the same approaches might not be useful;
- whether hydrophobes, fire retardants etc might not be as readily bonded to the modified fibre as adhesives;
- whether by control of the water reactivity of the fibre, some resistance to biodegradation might be achieved without the use of biocides.
- whether it is possible by this route to make fibre of controlled absorbtivity for water (for biomedical applications, thickeners, consistency adjusters for drilling muds etc) or for organic solvents (for solvent purification, clean-up of spillages, chromatographic purposes etc).
- whether fibre could be chemically modified to make it wettable by commodity thermoplastic polymers, thereby making it possible to use such polymer/fibre mixtures in the production of cheap mouldings, post-mouldable sheeting etc.

The possibility of combining chemical modification with steam injection technology is discussed in (g) below. The need for substantial investment in equipment in order to bridge the gap between laboratory experiments and processes viable industrially is discussed in (c) below.

(b) **Design of improved formaldehyde based adhesives for wood based composites.** The majority of the existing wood composites industry depends on the use of formaldehyde based adhesives (mostly urea formaldehyde (UF), melamine formaldehyde (MF) and phenol formaldehyde (PF) resins). It is unlikely, for reasons of cost, that resin systems based on chemical modification of the fibre surface (see (a) above) will penetrate significantly into the market for adhesives for commodity (flat-pressed) composite products. There is thus a need to improve the performance of conventional resins.

An obvious goal in the work on the chemical modification of fibre surfaces is the achievement of a primary valence bond between adherend and adhesive. However, there is evidence (Bolton, Dinwoodie and Beele, 1985; Beele, 1983) that some fractions of UF resins penetrate into the cell wall. If this is true, it is likely that there is an interphase of interdiffused resin and wood polymers. Even in the presence of water, it is unlikely that separation of the resin and wood phases would occur. So if penetration of the cell wall really does occur, it may not be as important to form primary valence bonds with the cell wall. The diffusion approach has the secondary advantage that wood cell walls weakened in the preparation of the particle surface may be strengthened by the diffusion of the resin polymer into them. Further work is needed to confirm that cell wall penetration really does occur (Bolton, Dinwoodie and Davies, 1988), and to see whether a resin system comprised of a low molecular weight fraction (for cell wall penetration) and a high molecular weight fraction (for gap-filling etc) offer any advantages (Stephens and Kutscha, 1987).

Other work at Bangor has shown that, in some instances at least, cured UF resins are less water reactive than cured PF resins, either because the latter are inherently more sorptive, or because of the affinity of the alkali in them for water (Irle, 1987: Bolton and Irle, 1987: Irle and Bolton, 1988). For whatever the reason, PF resins adsorb more water than UFs from an environment of fixed relative humidity, and this seems to plasticise the PFs. It seems likely that the PFs are for this reason more able to withstand the high stresses associated with composite "swelling". But it also seems that the achievement of flexibility through plasticisation with water, makes PF bonded composites creep more under sustained load. If it were possible to make resins more flexible (say by inclusion of a folded or coiled chain structure in the polymer network) it might be possible to improve their water resistance in composites without increasing their propensity to creep.

(c) **Development of adhesive systems for fibre bonding.** In recent years a new dry-formed fibre based panel, medium density fibreboard (MDF), has appeared on the market. It is likely that it will eventually capture much of the market for non-structural flat pressed panels in the furniture industry.

The technology of making such fibre based products is rather different from that used with other composites : a pulp slurry (> 50% water) leaves a steam-pressurised refiner, has resin added to it, and is then passed through a high temperature drier. Very little work has been done on the ideal resin characteristics for such a system : it is not known how the application of resin to a pulp suspension, or the subsequent exposure of the mixture to high temperatures, influences the performance of the composite.

It is also believed that, for a variety of reasons, the chemical modification research referred to in (a) is most likely to find a commercial application in the modification of fibre, not particles. The technology of applying the reagents to the fibre is likely to be similar to that used in the MDF industry.

Laboratory research in these areas is difficult because

- pulped fibre flocculates and aggregrates as it dries; also oxidative changes at the fibre surface occur readily. Neither of these effects is readily reversed. As a result, commercially available fibre is not a satisfactory raw material for research on chemical modification of fibre.

- the nature of the environment in which the adhesive will be applied and dried is impossible to simulate in the laboratory.

Progress in these areas is therefore dependent on the availability of a pilot scale facility for the manufacture of fibre, resin application and fibre drying. Without this facility, translation of the chemical modification research into viable new high performance products will be impossible. Equally, a fundamental understanding of an existing commodity products will be difficult to obtain.

(d) **Reduction of strain reversal in composites exposed to water.** Extensive work at Bangor has analysed the factors responsible for thickness swelling in particleboards exposed to water : when the particle mattress is compressed, the resultant stresses may, or may not, relax (Izugbokwe, 1978; Razzali, 1985; and papers in preparation). If they do not, they can be released in the presence of water and cause strain reversal. Strain reversal causes much particleboard "swelling" and this, in turn, is likely to cause failure of the wood-adhesive bonds. There is thus considerable potential for improvements in the performance of plant fibre composites without changes in the adhesive (Bolton, Humphrey and Kavvouras, 1988c). For example, in cement bonded particleboards, stress relaxation is enhanced, with the result that the boards show excellent stability in the presence of water. It has been shown that this is largely the result of the presence of alkali in the cement (Lloyd, 1984; and paper in preparation), this raises the possibility that the alkali in some PF resins may improve stability also). It may be possible to harness this effect in the production of dry formed composites.

Work in this area on fibre composites has not been possible to date because of the lack of the pilot scale fibre producing facilities referred to in (c).

(e) **Improvement of the board pressing model and prediction of bond strength development.** Previous work at Bangor had demonstrated the power of simulation models for the prediction of heat and mass transfer during the pressing of particleboard (Bolton and Humphrey, 1988; Bolton, Humphrey and Kavvouras, 1988a, b, c; Humphrey and Bolton, 1988a, b). Improvement of the accuracy of the model has been hampered by the impossibility of modelling events during press closure, and the lack of a rigorous treatment of mattress densification and the resultant changes in mattress permeability. This has arisen through the lack of sound experimental data to use in some areas of the model. Now that work on the density-permeability relationship (Bolton at Forest Products Laboratory, Madison, papers in preparation) and on mattress rheology (Humphrey at Oregon State University) is nearing completion, a second generation model could be developed. Prediction of residual stresses in the board, bond strength (see below), board stability, and minimum press time are foreseen. The likely benefits of this are seen as :

- the improvement of existing processes. (The model might eventually become a tool for controllers of industrial plant interested in predicting the effects of proposed changes in process variables):

- the development of a rigorous understanding of the relationship between the curing conditions inside laboratory boards and full-sized industrial boards:

- improved efficiency in the development of new products and processes.

So far no work in this area has been done on fibre composites because of the complete lack of information on their basic properties (water reactivity, thermal conductivity, permeability and the effects of product density on these), and also because of the absence of pilot scale product manufacturing facilities which could be used to verify the predictions of the model.

Past work at Bangor has also involved measurement of the strength development of UF resins between wood veneers at a variety of steady state temperatures (Bolton and Humphrey, 1977; Humphrey and Bolton, 1979). This has made it possible to predict the rate of strength development in the unsteady state temperature environment inside a mattress being pressed (Humphrey and Bolton, 1986). However, this has been done for one UF resin only. While there is evidence of some similar work in industry in North America and the USSR (Kreibich, 1981; Denisov, 1978, Sosnin and Denisov, 1968) very few data from this work have been published. DMA and similar techniques are beginning to be applied to the measurement of development of stiffness (E) of resins, but stiffness is often of less interest than failing load in composite production. There is thus a clear need for more work on the rate of bond strength (i.e. failing load) development. In none of the work published to date is the moisture content of the adherend, or the water vapour pressure, controlled. With resin systems curing by condensation reactions there is clearly a possibility that bond strength development may depend on water vapour pressure, so future work must consider this variable. Some work in the area is being done under the direction of Humphrey at O.S.U. (Ren, 1988).

(f) **Simulation of industrial pressing on laboratory presses.** At a more practical level, much research on resin development is carried out on laboratory presses. However, the temperature and water vapour pressure inside commercial panels during manufacture can be very different from that inside small laboratory boards (Humphrey and Bolton, 1988b), with the result that resins developed in the laboratory may not cure satisfactorily in industrial practice.

Using data on temperature and vapour pressure variation observed in a particular industrial operation, and computer controlled equipment based on a prototype developed for different purposes by Geimer and Bolton at F.P.L., it should be possible to simulate the industrial operation on laboratory presses.

(g) **Steam injection pressing.** The steam injection pressing method developed by Geimer, and now a feature of a number of new particleboard plants being installed by Siempelkamp, is obviously going to have a large impact on industry. Present thinking is that the process will only be viable economically with thicker boards (>25 mm), where pressing by conventional means is slow. The full potential of the process has probably not been recognised : in addition to increasing production rates, it also offers significant potential for :

- manufacture of flat-pressed and moulded fibre products as opposed to flat-pressed particleboards. It is even possible that selected parts of mouldings could be densified (and strengthened) using this technology;

- enhancing stress relaxation in the mattress, thereby reducing thickness swelling of the product when exposed to water;

- facilitating injection of gas phase reagents into the mattress. Gas phase reactions are attractive because penetration of the reagent into the fibre material should be much easier. However, on its own this approach might not be justifiable because of the cost of a pressurised reaction vessel. It should be possible to avoid this extra cost by using the steam injection/ evacuation system.

Bolton at U.C.N.W., Humphrey at OSU and Geimer at FPL are presently making a joint application for U.S. Government funding for work on steam injection pressing. The work proposed should provide a fundamental understanding of the process (which has been developed empirically), and thus facilitate the research proposed above.

(h) **Development of moulded products.** The most attractive markets for modified fibre involve complex shapes and the minimisation of weight (eg aircraft and exterior car components. Considerable input from a materials engineer will be needed to work out how best to use the new materials for the production of semi-load bearing structures. This work will have to be done in conjunction with a polymer technologist, working on the methods of forming complex shapes (blow moulding, injection moulding etc). These are areas in which we presently lack expertise.

(i) **Developments in mechanical pulping technology.** The pilot plant outlined in (e) above is ideal for any work involving manipulation of processing variables in refiner-groundwood or thermomechanical pulping. A particularly interesting possibility at present is that of using biological pretreatment (controlled rotting) to reduce the energy requirement in mechanical pulping by 20 to 25% (see Eriksson and Kirk, 1983, for example). The implications of such a pretreatment for the surface chemistry and processing characteristics of the fibre have not been investigated: much work needs to be done in these areas before such preteatments could be used commercially.

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LE LIN et ses Applications Textiles

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"TEXTILES A USAGES TECHNIQUES - APRES TECHTEXTIL 89"

Mardi 10 et Mercredi 11 Octobre 1989

I T F - LYON - Avenue Guy de Collongue - B.P. 60 - 69132 ECULLY CEDEX

LE LIN et ses Applications Textiles

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I - INTRODUCTION

Le lin et les fibres libériennes en général constituent sans aucun doute les premières fibres que les hommes aient utilisées pour des applications techniques. En dehors de l'usage vestimentaire (voiles, cordes, filets, sacs...), ces fibres de lin ne sont pas du coton ou de la laine, facilement accessibles, car elles sont liées très intimement au parenchyme et au cortex de la plante, et en outre, elles se trouvent associées entre elles très fortement par des ciments pectoligneux et des édifices de liaisons salines complexes et encore mal connus.

En fait, ces fibres "renforcent" une "matrice" cellulosique pecto-ligneuse que constitue la plante : ce renforcement du composite est du type périphéro-axial parfait et dans ce renforcement, les problèmes de distribution spatiale des fibres est parfaitement maîtrisé (anisotropie parfaite) et surtout l'interface entre fibres et entre fibres et matrice est exemplaire.

A tel point que l'extraction des fibres des plantes (de ce matériau, un composite naturel, est un véritable challenge que l'homme a confié depuis des millénaires aux effets très mal compris et maîtrisés de la nature (rouissage de la plante sur le sol du champ) et à l'action mieux contrôlée, mais plutôt brutale des marteaux de la teilleuse, des peignes de la grande peigneuse ou des dents et aiguilles de l'ouvreuse et de la carde...

Ces opérations d'extraction permettent d'obtenir des faisceaux de fibres plus ou moins longs, plus ou moins fins dont la forme, la constitution chimique, et les propriétés s'éloignent beaucoup d'autres fibres que l'on assimilent au lin, à savoir coton et viscose...

Si l'on veut utiliser le lin à des fins techniques, tendance qui se confirme sérieusement comme je vous l'indiquerai plus tard, ou si l'on veut "copier" un peu le lin et ses possibilités, il convient tout d'abord de le comprendre mieux.

II - SPECIFICITES MORPHOLOGIQUES DU LIN

Les éléments "lin" qui sont livrés à l'industrie textile sont donc des assemblages de fibres, matériaux composites souples, complexes sur le plan morphologique, faits de fibres élémentaires très fines (Ø 10 µ) et de longueur comprise entre 10 et 60 mm, et aussi d'éléments étrangers et incrustants.

De tels faisceaux montrent, sous le microscope électronique à balayage, des "blessures" fréquentes et nombreuses (plis, bourrelets, fissures...). Ces blessures affectent soit la partie extérieure des fibres des faisceaux, soit toute la profondeur. Des examens morphologiques très fins, conduits à I T F sur fibres individuelles, ont parfaitement révélé la perturbation structurale profonde à l'endroit d'une "blessure" visible à la surface d'une fibre élémentaire.

J'emploie volontairement le terme "blessure", car dans la plante verte, la fibre native, prélevée, disséquée avec grand soin par des mains expertes, ne révèle pas de blessures apparentes sous le microscope optique, en vue longitudinale. Il faut toute la pertinence de l'examen en lumière polarisée pour révéler quelques zones potentiellement fragiles de cette fibre native. De telles "blessures" se développent et s'accroissent tout au long du cycle d'extraction et de travail de la fibre et je vous en apporterai la preuve plus loin.

III - SPECIFICITES STRUCTURALES DU LIN

Deux mots simplement sur ce point pour rappeler et insister sur le fait que le lin n'est pas fait de cellulose pure, mais, dans sa présentation classique en faisceau, c'est un matériau complexe fait de 80 % de cellulose associée à des hémicelluloses, pectine, lignine et autres constituants minéraux. Ces "charges" non cellulosiques peuvent être incrustées intimement dans les fibres et entre les fibres. Une coupe transversale de fibre examinée en microscopie électronique à transmission, révèle très bien les incrustations d'hémicellulose, croissantes de la périphérie au centre de la fibre. Ces charges affectent l'organisation cristalline, la cristallinité de la cellulose, qui apparaît (diagrammes de microdiffraction électronique), plus grande en périphérie de la fibre. Les fibrilles cristallines de cellulose sont extrêmement orientées dans l'axe de fibre.

IV - SPECIFICITES DES PROPRIETES MECANIQUES

Une fibre élémentaire de lin, soumise à une sollicitation en traction, va toujours se rompre au niveau de l'une de ces nombreuses blessures visibles en surface.

Mais, phénomène important pour le lin, on peut créer à souhait ces blessures en faisant subir à la fibre de lin des efforts en compression axiale ou en cisaillement transversal. On arrive aussi à créer de véritables dislocations structurales, qui peuvent s'accompagner de fibrillations longitudinales locales.

Ces fibres élémentaires se distinguent des autres fibres naturelles telles que le coton et la laine par leurs extraordinaires propriétés mécaniques, qui les font comparer aux Aramides. Certes, au fur et à mesure que le nombre de blessures qui affectent la fibre augmente, ses performances mécaniques décroissent.

Filaments - Fibres pour composites

Situation des fibres de lin individuelles et natives

	Diamètre μ	Masse volumique g/cm³	Ténacité N/tex	Contrainte de rupture Mpa	Module d'élasticité Gpa	Allongement de rupture %
Polyester haute ténacité (filament)	21 - 31	1,38	0,73 - 0,83	1 100 - 1 140	12 - 15	11 - 14
Verre E	5 - 24	2,60	0,92 - 1,3	2 400 - 3 400	73	3,8
Aramide (PPTA)	13	1,44	1,9	2 760 - 3 150	60 - 90	3,4
Lin (fibres)	13,7	1,2	1,2	2 000	85	2,4

V - LES FIBRES DE LIN ACCESSIBLES SELON DES PROCEDES D'AFFINAGE

↔ *Affinage mécanique* : L'affinage mécanique du lin permet, en partant de matières de bonne qualité, bien rouies, d'obtenir une bourre de fibres courtes à des niveaux de clivage différents. Ces procédés mécaniques sont installés chez les producteurs-teilleurs de lin.

↔ *Hydrolyse Flash* : Procédé développé à I T F, aujourd'hui au stade pilote, permet d'obtenir du lin ultra affiné (principalement des fibres élémentaires), à partir d'un procédé transféré de l'industrie du bois (explosion du bois). Cette technique permet de partir de matières de base grossières, peu ou pas rouies. Les possibilités nouvelles offertes par cette matière, par rapport au lin traditionnel ou au lin affiné mécaniquement, sont essentiellement dues à :

- un taux de clivage très élevé conduisant à une forte individualisation des celluloses fibreuses élémentaires,

- une désincrustation de la fibre élémentaire très poussée. Cette caractéristique est l'une des revendications majeure du brevet ITF,

- une propreté très élevé au niveau de la surface des fibres : le ciment pecto-ligneux et la lamelle mitoyenne ont disparu.

VI - OUVERTURES POSSIBLES DU LIN VERS LES MATERIAUX TECHNIQUES

De la voile d'antan ... aux plaquettes de frein de nos voitures de course ... la presse vient de nous apprendre récemment l'utilisation du lin-fibre en association avec le graphite pour faire un composite efficace au freinage.

C'est aussi vrai que le lin a "mené le monde en tout sens" pour citer Pline, qui pensait essentiellement à la voile de nos ancêtres.

Sous sa forme affinée, et surtout ultra affinée, le lin-fibre peut se présenter comme un outsider par rapport aux fibres chimiques modernes les plus performantes pour des applications de renforcement de matériaux (non thermique).

On peut penser :

- renforcement de résines thermoplastiques (phénomène de transcristallisation certainement très important du fait de la forte cristallinité et anisotropie de la surface de la fibre de lin),

- renforcement de ciment ou de béton : le marché visé est la substitution de l'amiante pour les produits type amiante-ciment. Il semblerait que l'Allemagne engage un vaste programme de culture du lin, plante à fibres, pour extraire des fibres techniques pour un tel marché. Compte tenu du climat local peu favorable à une extraction des fibres traditionnelles, seuls des procédés nouveaux type "Hydrolyse Flash" seraient appropriés. D'ailleurs des équipes allemandes puissantes travaillent dans cette direction

- renforcement de bitume, d'élastomère, de graphite, etc...

Sous la forme d'étoffes tissées ou nontissées, le lin a également son mot à dire dans les utilisations techniques :

- Il est présenté comme un géotextile biodégradable à l'état tissé (les Hongrois Buda Flax exposent régulièrement des toiles de lin très lourdes pour cette application). Dans le même esprit, on trouve le jute (meilleur marché) → Géojute.

- La forme nontissée (surtout à partir de fibres ultra affinées en pur ou mélange) peut trouver des applications en géotextile (renforcement temporaire) ou agrotextile (nappes de support d'engazonnement de pentes, etc...).

- La forme traditionnelle, dans laquelle le lin possède sa structure en faisceaux (fibres + ciments pectiques), permet d'atteindre des performances mécaniques assez remarquables par des manipulations chimico-mécaniques conduisant à des toiles pré-contraintes. Un cas remarquable est celui des toiles à peindre ou des toiles de rentoilage de tableaux : marché très important où les fibres modernes les plus performantes (Kevlar, verre, polyéthylène) n'ont pas réussi à détroner le lin.

Avec ce gendre de manipulations, on arrive, avec des toiles de lin de 200 g/m² à des performances du type :

- Allongement rupture :	8 %
- Embuvage des fils :	1 %
- Résistance mécanique :	supérieure à 3 kN/mètre linéaire.

Les astuces de ces manipulations consistent à faire des "massages" de la toile "supertendue" au mouillé : sous l'effet de l'eau et du gonflement des fibres, la toile se tend comme une "peau de tambour" et sous l'effet du "massage" et de l'eau, les ciments sont déplacés, redistribués dans le plan de l'étoffe et permettent de fixer la toile dans sa nouvelle présentation lors du séchage. En répétant l'opération plusieurs fois, on arrive à la proposition de toiles extrêmement pré-contraintes, sans capacité de fluage de contexture. Excellents supports pour faire de l'enduction ou bien des contrecollages renforçant (type rentoilage de tableau).

Les mêmes opérations conduites à l'état sec évidemment ne donnent rien, sinon une abrasion de la toile : ceci est évidemment très compréhensible dès que l'on a consigné les spécificités morphologiques, structurales et mécaniques du lin que je vous ai présentées en début de cet exposé.

VII - CONCLUSIONS

Les fibres naturelles ne doivent pas être oubliées dans les applications techniques. Il faut d'abord bien les comprendre pour mieux les utiliser.

Elles peuvent aussi servir de modèles car elles recèlent des faits morphologiques et des propriétés encore inégalées : c'est le cas du lin, mais aussi de la laine (micro-composite), du fil d'araignée et enfin des fibres creuses (modèles de confort) qui constituent les fourrures des animaux du Grand Nord.

JANUARY 1990

Performance

Fire
Pyrok Five Star Board has been successfully tested in accordance with BS 476 'Fire Tests on Building Materials and Structures.'
For Parts 5 and 6 (ignitability and fire propagation), an index performance of 2.0p was achieved which qualifies as a Class 0 Material under the Building Regulations.
For Part 7 (surface spread of flame), Pyrok Five Star Board achieved a performance of Class 1.
For Part 22 (tests on constructions), Pyrok Five Star Board has been successfully tested in a range of different constructions for various lengths of time of fire resistance.

Acoustic
Airborne sound reduction varies between 30 and 37 dB according to board thickness. When used in stud partitioning, reductions of over 50 dB can be achieved.

Alkalinity
Pyrok Five Star Board has a pH value of 11.5 – 12.6.

Biological
The board shows resistance to fungus, insects and vermin.

Dimensional Stability (RH 65-90%)
For each 30% change in RH thickness increases 0.50% and length 0.10%.

Electrical
Pyrok Five Star Board when tested to BS 5901 is resistant to tracking and therefore can be used as an electrical apparatus backboard.

Frost Resistance
Data received from BRE on 18mm board offer 50 cycles of testing between −20°C and +20°C confirm no change in thickness or M.O.E. and a reduction of 7% on M.O.R.

Heat
Thermal conductivity K-value is 0.23 w/m°C. Linear thermal expansion is 0.012 mm/m°C.

Production Tolerances
Tolerances on dimensions are as follows (ISO std.): on length and width ± 5mm, on thickness 6mm-12mm ± 0.7mm, 12mm-20mm ± 1.0mm and for thicknesses above 20mm ± 1.5mm.

Swelling on Water Immersion
Data received from BRE on 18mm board after 24 hrs gives swelling on thickness 0.86%, width 0.07% and length 0.12%.

Water
Moisture content is 9% ± 3% by weight. Pyrok Five Star Board will adjust to ambient moisture condition and can reach up to 30% in high humidity.

Structural

Density	1250 kg/m^3 Av.
Modulus of rupture	9-13 N/mm^2
Modulus of elasticity	4500 N/mm^2
Compressive strength	15 N/mm^2

FIVE STAR PYROK ★★★★★ BOARD

Cement/
Wood particles.

Technical data summary

Width 1220 mm Length 2440, 3050 mm
Thickness 6, 8, 10, 12, 16, 18, 20, 24, 28, 32, 40 mm.

This leaflet has been produced to demonstrate some of the results achieved by Pyrok Five Star Board

Performance

Tensile Strength	Perpendicular to surface	0.35 N/mm^2
	Parallel to surface	4.0 N/mm^2

Extraction Resistance of Screws

Thickness	Face	Edge
12 mm board	980 N/10 mm depth	500 N/10 mm depth
18 mm board	1390 N/10 mm depth	770 N/10 mm depth
24 mm board	1620 N/10 mm depth	920 N/10 mm depth

Extraction Resistance of Nails

Thickness	Face	Edge
12 mm board	400 N/10 mm depth	130 N/10 mm depth
18 mm board	530 N/10 mm depth	240 N/10 mm depth
24 mm board	830 N/10 mm depth	370 N/10 mm depth

Tests

Legend for chart over.

AIRO	Acoustical Investigation and Research Organisation Ltd.
BRE	Building Research Establishment.
FIRTO	Fire Insurers' Research and Testing Organisation, Melrose Avenue, Borehamwood, Hertfordshire WD6 2BJ, England.
GLC	Greater London Council, Department of Architecture and Divic Design, Middlesex House, 20 Vauxhall Bridge Road, London SW1V 2SB, England.
Warrington	Warrington Research Centre, Holmsfield Road, Warrington WA1 2SD, England.
Yarsley	Fulmer Yarsley Technical Centre, Trowers Way, Redhill, Surrey RH1 2JN, England.

Pyrok Building Products Limited, Brue Way, Walrow, Highbridge, Somerset TA9 4AW.
Telephone: 0278 780111 Fax: 0278 788137

Tests

Category	Description	Tests (T) or Assessments (A)	Result	Authority	Test Number	Date
Structural						
	Tensile strength parallel to board plane	(T)	6.6 N/mm²	Yarsley	G82902/1	10.08.88
	Compressive strength parallel to board plane	(T)	22 N/mm²	Yarsley	G82902/1	10.08.88
Bonding Strength						
	Board to Board (BS 5980 – 1980)	(A)	Passed	—	—	—
	Board to ceramic tiles	(A)	Passed	—	—	—
	Board to wood	(A)	Passed	—	—	—
	Board to marble	(A)	Passed	—	—	—
Thermal						
	Conductivity	(T)	0.23 W/m°C	Yarsley	C82452/2	22.07.88
	Linear Thermal expansion	(T)	0.012 mm/m°C	Yarsley	G82692/1	07.06.88
Organic						
	Fungus attack	(T)	No effect	BRE		
	Termite attack	(T)	Resistant	BRE		
Fire						
General	Toxicity when heated	(A)	Harmless			
	Fire resisting cavity barriers above false ceiling	(A)	Permitted	GLC	AB/BR/3/ 137236	05.09.83
Tested to BS 476	Part 3 External fire exposure roof test using 12 mm thick CBPB	(T)	Ext FAA	Yarsley	C75284/2	01.09.84
	Part 5 Ignitability	(T)	Does not ignite	Yarsley	J82157/4	16.05.88
	Part 6 Fire propagation	(T)	Class 0	Yarsley	J82157/5	16.05.88
	Part 7 Surface spread of flame (on outer surface)	(T)	Class 1	Yarsley	J82157/6	16.05.88
Part 22 Fire Resistance of constructions						
Timber stud partitions						
	10 mm thick on each side (no cavity fill)	(A)	½ hour	Yarsley		
	12 mm thick on each side (no cavity fill)	(T)	½ hour	Yarsley		
	12 mm thick Pyrok on each side (mineral wool in cavity)	(T)	2 hours	Yarsley	J82157/2	05.05.88
Steel framed partitions						
	12mm thick Pyrok on each side (no cavity fill)	(A)	½ hour	Yarsley	J83226/10	24.08.89
	12mm thick Pyrok on each side (mineral wool in cavity)	(T)	1 hour	Yarsley	J83226/9	22.06.88
	16mm thick Pyrok on each side (mineral wool in cavity with fillets)	(T)	1½ hours	Yarsley	J82157/3	22.06.88
	16mm thick Pyrok on each side (tongue and grooved joints - mineral wool in cavity)	(T)	2 hours	Yarsley	J83226/4 & 11	23.12.88
	18mm thick Pyrok on each side (mineral wool in cavity with fillets)	(T)	3½ hours	Yarsley	J83226/2	18.10.88
	12 + 18mm thick Pyrok on each side (mineral wool in cavity with fillets)	(T)	4½ hours	Yarsley	J83226/6	12.04.89
Shaft wall systems						
	12mm thick Pyrok (two layers, mineral wool in cavity	(A)	1 hour	Yarsley	J83226/14	4.1.90
	16mm thick Pyrok (two layers, mineral wool in cavity)	(T)	2 hours	Yarsley	J83226/13	5.10.89
	16mm thick Pyrok (Ditto but double construction with air gap)	(A)	4 hours	Yarsley	J83226/15	4.1.90
Miscellaneous tests (vertical)						
	Single skin 18 mm thick	(A)	½ hour	Yarsley		
	Single skin 28 mm thick	(A)	1 hour	Yarsley		
	Two skins 18 mm thick separated by 75 mm air gap	(A)	1½ hours	Yarsley		
Upgrading fire doors						
	6 mm thick on both faces	(A)	½ hour	Warrington		
	6 mm thick on one face only	(A)	½ hour	Warrington		
Specific development testing						
	Internal lining for curtain walling to BS 476 Part 22.					
	Above floor assembly consisting of 18 mm thick on each side bolted to mild steel balusters with mineral wool in cavity	(A)	1 hour	Yarsley		
	Below floor slab assembly consisting of 18 mm thick single skin with 14 mm thick 'Rockpan' bonded to one face, assembly supported by steel stirrups	(A)	1 hour	Yarsley		
Steel column protection						
	Pyrok Five Star with Rockwool Conlit System 150P	(T)	1 to 4 hours	Information available on request.		
Sound						
	6-40 mm thick single boards of Pyrok airborne attenuation	(T)	30-37 dB	AIRO	L/1946	15.06.88
Timber stud partitions						
	10 mm thick on each side (mineral wool in cavity) airborne attenuation	(A)	41 dB			
	10 mm thick on each side plus ceramic tiles on one side (no mineral wool in cavity) airborne attenuation	(A)	47 dB			
Steel framed partition						
	16 mm thick on each side (mineral wool in cavity) airborne attenuation	(A)	55 dB			
Electric						
	Comparative tracking index	(T)	575	Yarsley	C82452/1	20.04.88
	Erosion Depth	(T)	0.7 mm	Yarsley	C82452/1	20.04.88
Chemical						
	Oil resistance	(A)	Satisfactory			

NB. Copies of official test documentation available on request.

Fidor

Fibre Building Boards Technical Information

CI/SIB
(1)

'MDF' (medium density fibreboard)

January 1988
Product Data Sheet
PD/7 (Edition 4)

IDENTIFICATION & CHARACTERISTICS

Description

Homogeneous sheet material, manufactured from wood fibres and synthetic resin binder, usually smooth both sides, pale sand in colour, 3 to 60mm thick. Generally more dense than hardwoods.

Characteristics

Because of its homogeneous nature, MDF has machine-ability as its premium property. It can be sawn and routed easily, whilst intricate machining and moulding can be carried out without exposure of core voids. There are no end grain or splintering problems. The face is smooth and flat so it is particularly suitable for painting and foil-laminating. Tests show that MDF has physical properties as good as or better than the best furniture grade particle boards. In many respects it may be treated as high quality solid timber, but without knots or grain.

Moisture Resistant MDF (MDFMR) has all of the properties of standard MDF with an improved resistance to moisture.

Related Documents

A specification for MDF is included in the 1985 Amendment to BS 1142: Parts 1 and 2, which is in the process of being revised.

The wet cyclic test for MDFMR is contained in BS 5669: 1979.'Specification for Wood Chipboard and Methods of Test for Particle Board'. This test(which is the equivalent of the French V313) will be included in the revised BS 1142.

FIDOR technical bulletin TB/004 – MDF Machining.

The data given in this leaflet are general, round-figure values accumulated from laboratory test results and manufacturers' literature. For more exact figures on a specific product individual manufacturers should be consulted on actual tests made. Marketing organisations for individual brands are given in the FIDOR Brand List.

DESCRIPTION

Composition and manufacture

MDF is made by a dry-forming process.

Sheet sizes commonly available are 1220 and 1525mm wide x 2440, 2745, 3050 and 3660mm long. Also 1830mm x 1830mm. Other lengths and widths can be obtained, as well as cut-to-size pieces.

Thicknesses available cover an extensive range between 3 and 60mm.

Production tolerance

	Typical manufacturers' specification (mm)	BS 1142 Specification (mm)
Length & Width	± 2.0	± 3.0
Thickness	± 0.15	± 0.3
Squareness	3.0 diagonal	
Straightness	± 1.6	

Densities lie in the range 640-860 kg/m³, a typical board density being 730 kg/m³. A 12mm thick board, for example, would weigh about 8.7 kg/m². Being made from the same type and size of wood fibre throughout, the variation between centre and face densities is not great but most boards are more dense at their surfaces. Thus the less dense and therefore lighter boards can still have satisfactory surfaces for many applications.

Surface texture Boards are supplied sanded smooth both faces by the manufacturer prior to delivery.

Smoothness of MDF surfaces makes them ideal for painting and the application of thin paper or PVC foils. Generally, the finished surface remains smooth despite in-service variations of the moisture content of the board itself.

Colour is generally pale sand.

PROPERTIES

Climate effect

Like other timber-based products, MDF is hygroscopic and its dimensions change in response to changes in humidity. A change in relative humidity from 85% to 35% results in about 0.25% shrinkage in the plane of the board and about 3% in the thickness. These are laboratory test results and changes of this magnitude are unlikely to occur in practice. MDF should be protected from rain and excessive moisture.

Table 1: Strength properties

Property	Thickness (mm)	Range of values (N/mm²)	BS 1142 Value (N/mm²)
Transverse Internal Bond	12-19	0.6-1.5	0.6
Modulus of Elasticity	15-19	2100-4000	2500
	22-30	Max. 3500	2500

Deflection – see shelf loading and Table 3

Surface soundness

Surface soundness provides a measure of the strength of the surface of a board material, and it is particularly relevant when the adhesion of decorative surfacing materials is considered. When surface soundness tests are applied to MDF, failure of its core is not uncommon, indicating that the true surface soundness is often higher than shown in Table 2.

Table 2: Surface soundness

Thickness (mm)	Range of values (N)
15/16	1900-3500
17/18/19	1500-3300

NOTE: Typical chipboard figures are 1300-2000N.

Shelf loading – deflection

MDF boards simply supported and spanning 600mm can support loads given in Table 3 before deflecting 2mm (span/300) at their centre. These figures indicate the suitability of MDF as the tops, bottoms or shelves of cabinet furniture.

Table 3: Shelf loading (sustained load)

Board thickness (mm)	Range of loads kg/dm²	Application *	Rating
16	1.39-1.8	Heavy Domestic/ Careful Contract	3
18	2.16-2.7	Normal/Rough Contract	4
19	2.47-3.09	Rough/Severe Contract	5

* BS 4875: Strength and Stability of Domestic and Contract Furniture.

Water absorption

Complete immersion in water (Table 4) is not a realistic hazard for MDF but it may, very occasionally, absorb water through an edge; for instance in a kitchen or bathroom. Table 5 gives results of tests in which boards were stood on edge on a constant moist surface.

Table 4: Complete immersion

Time (hours)	Increase in Weight (%)	BS 1142 Value (%)	Increase in Thickness (%)	BS 1142 Value (%)
1	1.5-3.5	-	1.5-4.0	-
24	10-15	18	6	6

Table 5: Edge absorption after 24 hours

Distance from edge	Range of thickness swelling (%)
10mm	1.2 to 2.9
25mm	0.2 to 0.7

Wet Cyclic Test

The moisture resistant MDF boards currently available which have been subjected to the wet cyclic test described in BS 5669 produced the range of values shown in Table 6.

Table 6: Thickness Swell and Internal Bond

Property	Board Thickness (mm)	Range of Values	BS 5669 Value
Thickness Swell (%)	6-25	4.7-6.0	8.0
Internal Bond (N/mm^2)	6-19	0.30	0.25
	19-25	0.26-0.30	0.20

Moisture content varies with the relative humidity (r.h.) of the surrounding air from about 6.0% at 35% r.h. to 13% at 85% r.h. These values indicate that MDF reaches an equilibrium moisture content which is about a quarter to one third less than that of solid wood in the same environment.

Water vapour

Table 7: Dimensional changes due to changes in relative humidity from 35% to 85% at 20°C.

Range of percentage increase	
In length and width	In thickness
0.16-0.34 (BS 1142 value: 0.40)	1.3-4.4 (BS 1142 value: 6)

Durability of MDF is considered to be equal to that of other woodfibre building boards. Most types of MDF are recommended for interior use only.

WORKING CHARACTERISTICS

Applications: MDF is particularly used in the furniture industry for cabinet carcasses, drawers, rails, door frames, unit tops, mirror and picture frames – particularly where profiled edges, relief surfaces and one-piece framing is called for and where there is a need to eliminate lipping or edge banding.
In addition, MDF is used in substitution for solid timber, for the machining of consistent straight lengths of mouldings (skirtings, architraves, cornice mouldings, etc) and also in shopfitting and in partition systems.

Moisture-resistant MDF is used in potentially high humidity situations such as kitchens, bathrooms, window boarding and during building construction.

Cutting and machining: MDF can be worked with normal woodworking machinery to give a high degree of finish, particularly on profiled edges. Intricate machining and moulding can be carried out without the exposure of core voids.

Jointing: MDF can be jointed like other timber products using dowels, screws, pins, staples, inserts or adhesive. Care should be taken when using nails as these can delaminate boards when driven into board edges.

Screwholding conventional woodscrews can be used in MDF but in board edges may cause slight splitting if the pilot hole is not correct. Parallel-shank screws are more suitable for production work as there is less uncertainty about pilot hole diameter – see Table 10.

Table 8: Typical values for proprietary screw type in 16mm MDF

Pilot hole depth 1.5mm Face Screwholding strength (N)	Diameter 2.70mm Edge Screwholding strength (N)
1260	1060

BS 1142 test method: for 16mm thick board face screwholding – 1050N (min); edge screwholding 850N (min), using GKN 'Supascrew' No. 8. Decreasing the pilot hole diameter to 2.16mm will increase face screwholding strength but decrease edge screw-holding strength (by about 3%).

Table 9: Withdrawal loads* for No.6 woodscrews (3.45mm diameter) driven 13mm into MDF

Screw Type	Pilot hole (mm) Dia.	Depth	Range of mean values (N) Face	Edge
Standard	1.5	6	680-1070	360-950
'Twinfast'	1.5	6	600-1120	380-850
Standard	2.6	14	670-1370	430-1120
'Twinfast'	2.6	14	630-1790	580-1770

* When tested to BS 5669: 1979 'Tests for Chipboard' which gives a minimum value for edge screwholding of 310N.

Table 10 recommends pilot holes generally suitable for edge screwing without delamination. These holes may affect withdrawal strength, and smaller holes may be found satisfactory for some brands.

Table 10: Recommended pilot holes for edge fixing

Board thickness (mm)	Screw Size	Max. Pilot Hole Size * (mm) Dia.	Depth
	2	1.5	
	4	2.0	
9	5	2.4	Slightly beyond the full depth of screw*
12	6	2.5	
16	7	2.7	
18	8	3.0	

* These sizes reduce the risk of splitting although withdrawal strength may be marginally less.

The processing and use of waste straw as a constructional material

Paper presented by J.G. Mosesson to the world recycled resources conference in Manila

Definition

Straw is defined as the stems or stalks of certain cereals, chiefly wheat, rice, barley, oats and rye. It is sometimes confused with hay which is dried grass. It is more understandably confused with reed with which it has certain similarities. Indeed, in the Middle Ages the words were used interchangeably, particularly in connection with thatching. Today, however, the word 'reed' is more strictly defined as the tall straight stalks or stems of the water margin plants belonging to the genera phragmites and arundo. Hay and reed have clear uses and are not a by-product. Straw is a by-product of cereal production and, taking the world as a whole, is largely wasted.

Straw – a recycled source?

As will be shown later, at least half of the world's straw production is waste. It is waste in a by-product sense. Straw can be regarded as a carrier in the same way that a bottle or a carton is a carrier. When it has completed its carrying, it is 'spent'. The carton or bottle carries the solid or liquid to the consumer. The straw carries the cereal to the optimim environment. Much work has been done in recent years to try to improve on one of nature's carriers, straw. Not surprisingly, it has proved extremely difficult to do. Attempts have been made to lengthen, shorten, stiffen and reduce in nutrient. So finding uses for straw is a matter of recycling a waste, a matter of recycling one of nature's carriers as against a man-made carrier.

Material sources and energy sources – two of today's central concerns

Among today's central concerns, the finiteness of certain essential materials and the finiteness of additional sources of energy figure highly. Both are concerned with avoiding waste. In England, a Government Green Paper has recently been issued, entitled "War on Waste".

It is hoped that the present paper will demonstrate that straw, an annually recurring waste, can be converted into an effective material substitute, and also an energy saving substitute.

Geographical distribution of straw

Cereals, being one of man's basic foods, exist in all corners of the world where there is habitation. Indeed, being a natural product, straw exists where there is no habitation. Cereal, and hence straw production, has been a feature of society from its earliest beginning, from the time man ceased being a nomad. Perhaps straw was man's first waste disposal problem.

As a potential source material for building, it is highly significant that it exists in some of the world's least developed and neediest countries.

How much straw is there?

World figures for straw production are not published, so guesses can only be made. Taking the world's three major straw producing cereals – rice, wheat and barley – total estimated grain tonnage for 1978 is in excess of one thousand million metric tonnes. Taking an average over the three cereals and speaking only approximately, the weight of straw can certainly be taken to be equal to that of the grain.

Current uses/disposal of straw

Not all straw by any means is wasted. There are traditional uses going back to earliest civilisation in the form of using straw for bedding and fodder. In fact, this use remains today the single biggest area of consumption. Taking the three above-mentioned cereals on a world basis, it is likely that at least between a third and a half of the straw produced is treated by the growers as an unusable waste.

In addition to the above-mentioned principal use of straw as bedding and fodder, certain traditional crafts have used straw as a source material, including thatchers, hat makers and basket makers.

In more recent times, semi-industrial processes emerged including using straw for envelopes for glass transportation, woven matting, blinds and screens. All these craft and semi-industrial processes relied on receiving long selected stems of the type and quality produced when cereals were cut by hand with scythes. Hand harvesting still exists, particularly with regard to rice, but all world agriculture is moving towards greater mechanisation. Today most of the world's wheat, barley, rye, oats and dry rice is cut by combine harvesters. This technique breaks the straw up and renders it unsuitable for the above-mentioned craft and semi-industrial processes. In addition, plastics have proved to be an effective substitute. Today, in percentage terms, the non-agricultural industrial uses of straw amount to less than two or three percent of that used. Included in this percentage is paper manufacturing, industrially produced animal feed and building board manufacture.

Why change?

Why should this position change? What forces are at work? First there is the ever increasing world demand for source materials. But materials are normally only tackled when new techniques emerge which lead the way to more economical alternative means of production. Straw and any other sort of material is only interesting if it can be shown to be satisfactory on technical, commercial and acceptability grounds.

The properties of straw

The potential of straw lies in its chemical constituency and its physical consistency.

In the technical sense, there is very little that today's industrial chemists cannot do. It is entirely a matter of economics. Petrol can be made from straw. For economic reasons, the principal source materials for chemists are oil, coal and quarried material. It is only a matter of time before chemists turn to straw on a large scale for their chemicals.

In many cases, what materials to produce from straw and how to do it has been worked out. Major international companies, in an effort to be sure to be in the front line when the time comes, are running small scale chemical operations based on straw, currently running at a loss, biding their time to expand, in the meantime learning the practicalities.

For many years the paper industry has been keeping a close eye on straw, indeed using it on a limited scale. As yet the cost of chemically and physically breaking straw down to the base material required cannot match the exisiting sources of wood and recycled paper. Again, it is only a matter of time.

A third area, and perhaps the potentially biggest, is that of using straw as a source material in the building material industry.

Indeed, a process has existed for the last forty years which can convert straw into a building board in which there are no technical constraints, no commercial constraints; basically only the constraint that the building industry and the majority of building purchasers are deeply conservative.

Why develop new building materials?

We have already noted that there is world concern about diminishing materials and energy sources. Some materials and energy sources are being squandered through greed and extravagance. There are, however, certain fundamental human requirements, and high on the list is the need for food and shelter. The world over there is a massive shift from the countryside to towns. Man's tradition of growing his own food and building his own home is fast disappearing. More and more food is grown commercially, more and more houses are built commercially. These urban community services should be as close to the markets they serve as possible. An ideal position is for the by-product of one to be the basic source material of the other. Straw is such a product.

New qualities demanded of building materials

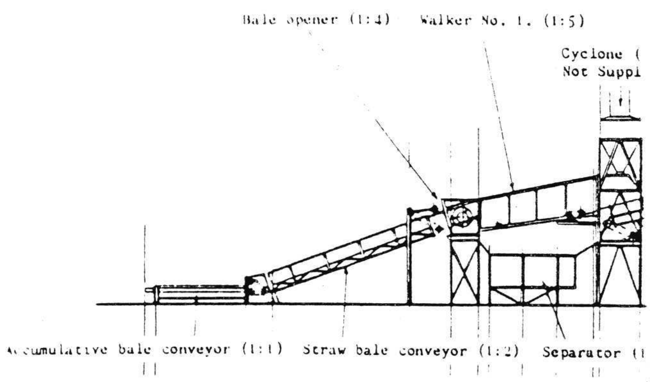
It follows from the concern about shortage of materials and energy that construction like any other consuming activity must be looked at from this point of view. This is extremely challenging since two of the most basic traditional materials in construction – cement and steel – are high consumers of energy.

They are also capital intensive, expensive on transportation and poor on insulation. On their own, they put additional energy demands on controlling the internal building environment, keeping it cool or making it warm.

In a world with mass demand for building materials, and where the poorest nation has the greatest demand, new criteria are emerging. Ideally, materials should be indigenously available, plentiful in supply, stable in raw material costs, be cheap in conversion, multifunctional, time saving in their use, low in energy consumption, insulating in performance, long lasting and easy to understand and use. A process has now been developed for manufacturing a building board from straw which meets all the above conditions, except the last – ease of understanding.

The Stramit straw conversion process

In the early 1930s, a technique was invented in Sweden for converting straw into a building board by means of heat and pressure. The technique was taken up and developed in England in the 1940s and 1950s, plants were subsequently established in some fifteen countries and has now become internationally known as The Stramit Process. At the heart of the process lies a discovery that straw, subjected to reasonably high temperature and pressure,releases its own internal resinous substances which make it possible to extrude a continuous board without the addition of resin.



Since most other building boards, such as plywood, chipboard and blockboard, rely on resin to bond the material, this factor is a vital key to the great economy of the system. This is, of course, especially true since the world oil price explosion in 1973 -most resins being oil based.

As a matter of considerable good fortune, a wide range of straw types has proved suitable for use in the process. Principal among these are wheat, paddy rice, dry rice, barley and rye.

Manufacturing technique

The manufacturing technique can be followed by studying the elevation and plan of a typical machine, shown in Figure 1, and pictures of the process, shown in Figures 2, 5, and 6.

Straw Feed Section

Straw would normally be baled in the fields for ease of transportation and brought to the plant. Bales are then loaded onto the accumulative bale conveyor (1:1) two abreast where the string or wire is cut and removed before the bales move onto the straw bale conveyor
(1:2) at the end of which is a bale opener (1:4). The bale opener loosens and spreads out the straw in an even mat. Provision is made for dust extraction at this point before the straw is passed at a controlled volume to a straw walker/separator unit, where it is cleaned and graded.

The two straw walkers (1:5) consist of a series of stepped paddles, inclined upwards and moving longitudinally in a reciprocating action, thus passing the straw forward while allowing chaff, stones, grain and short straw to fall by gravity onto a waste conveyor (1:6) which discharges into a separator (1:7) for controlled separation. The straw is ejected from the straw walker system and falls onto an inclined loose straw conveyor (1:9) which carries it to the top of the straw feed hopper (1:10) which feeds the straw to the reciprocating ram of the slab forming section (2:1).

The short but still usable straw which falls from the straw walker system (1:5) is separated from grain and impurities by the separator (1:7), pneumatically conveyed back to the loose straw conveyor (1:9) where it joins the main stream of longer straw moving towards the hopper (1:10). Reject short straw is thus kept down to a minimum. Grain and small stones are fed into different reject channels in the separator, the grain being bagged for subsequent sale, while the stones are dropped into a container. Finally rejected short straw is normally ground in a separate grinding plant and sold as animal food additive.

The level of straw in the hopper is maintained by means of photo-electric cells which actuate the starters of the drive motors of the bale conveyors (1:1) and (1:2), straw walkers (1:5) and the loose straw conveyor (1:9).

Slab Forming Process

At the bottom of the hopper, a set of mechanical fingers pull an equal amount of straw downwards for each stroke of the ram. With each stroke new straw is forced in between the top and bottom beds of the slab forming section (2:1) impacting it against the slab of straw already between the beds. When the friction between the straw and the beds, the tension of the paper liner and the weight of the slab is overcome, the slab will move forward.

The straw passes through a total of three sets of beds. In the first set, called the back cold beds, the straw is compressed into its final form. In the next set of beds, the back hot beds, which are heated by means of thermostatically controlled electrical elements, the straw is set permanently in its compressed state. From here the slab of straw enters the final set of beds, the front hot beds, heated in the same manner as the back hot beds. The paper liner is introduced between the back and front beds providing the slab with paper on both sides.

The paper liner, fed from two reels situated above and below the Stramit machine, passes through glue rollers and the pressure and heat from the bed plates bond the paper liner securely onto the straw slab. This glue requirement is minimal.

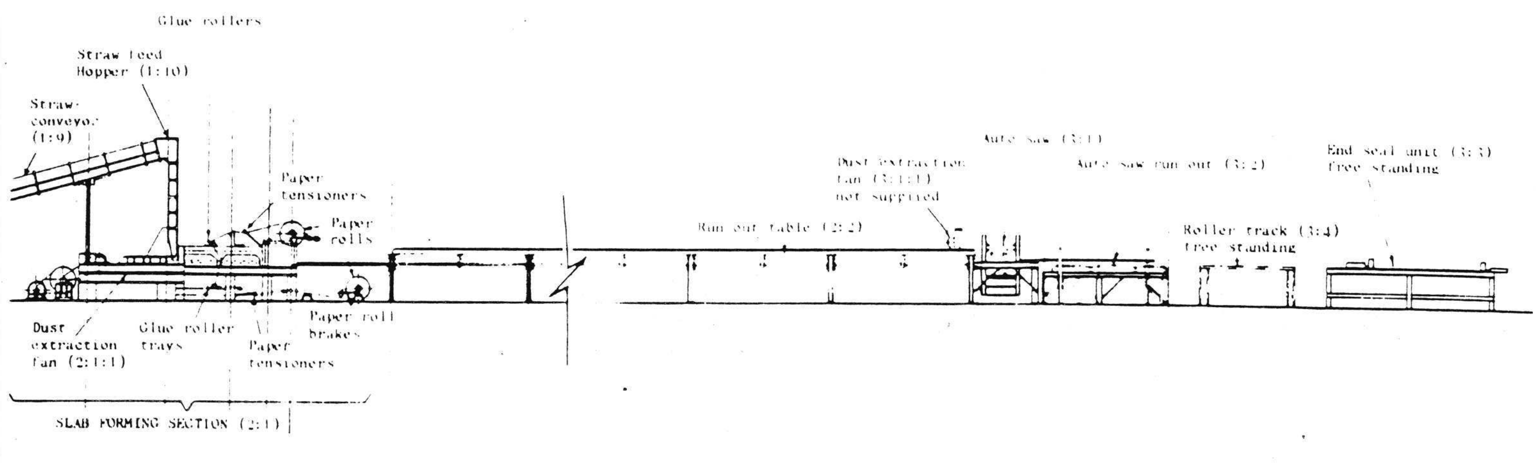


Fig 1. A Stramit machine: elevation and plan, type 1008.

Cut-Off and End Sealing Operation

The slab, after leaving the front hot bed, moves onto the runout table (2:2) at the end of which is an electrically driven automatic cross cut saw unit (3:1) moving longitudinally with the slab to give a right angled cut across the slab. The saw unit is fitted with a device for automatic measuring of lengths to be cut.

Factory Building Requirements

Figure 1 illustrates a typical Stramit machine in elevation and plan. It also sets out a typical factory layout. No unusual demands are r..ade on the building. Foundations need to be slightly reinforced at the slab forming section. The principal function of the factory superstructure is protection against the elements and security required.

Utilities Consumption

Figure 3 sets out the utilities required for strawboard production. It will be noted that there is no water requirement, and that demands on electricity and compressed air are modest by manufacturing standards. There is no industrial effluent problem.

Personnel

Figure 4 sets out the personnel required for a typical plant running on one, two or three eight-hour shifts.

Cost of Manufacturing Materials

By far the largest material cost is, needless to say, straw. It is a somewhat remarkable fact that in countries where strawboard is being produced, some straw producers will be spending money destroying their straw, while others will be being paid for it. Straw is generally regarded as an embarrassment to farmers in that they must get it out of the way quickly in order to get on with ploughing and sowing for the next crop. The efficiency therefore with which the straw is gathered, baled and transported to a strawboard factory is important for successful operation to all parties. It can be very misleading to quote figures of the value of straw per ton delivered to strawboard factories around the world. Suffice it to say as a guide that the range is between twenty and forty US dollars per ton. The cost of other subsidiary materials like paper liner, resin for bonding the paper liner and utilities such as electricity, represent a small proportion of manufacturing costs. And with the capacity of a typical machine being up to half a million square metres per year, the factory labour involvement of, say, twenty personnel also becomes a relatively modest proportion of the manufacturing cost.

Investment

So a simple process in theory, considerable skills surround the production of first class board. Experience over the years has therefore led to a policy where licensees enter into a composite package which includes the licensor installing the machinery, commissioning it and running the factory for an initial period. Technical production back-up and technical marketing back-up are also built into the package. It is extremely difficult to offer a generalised figure on the level of total investment in a strawboard manufacturing business. It might just be useful as a guide to say that potential new licensees are advised that total investment capital in factory, plant, raw materials stocks and working capital would probably be in the order of between one and one-and-a-half million US dollars.

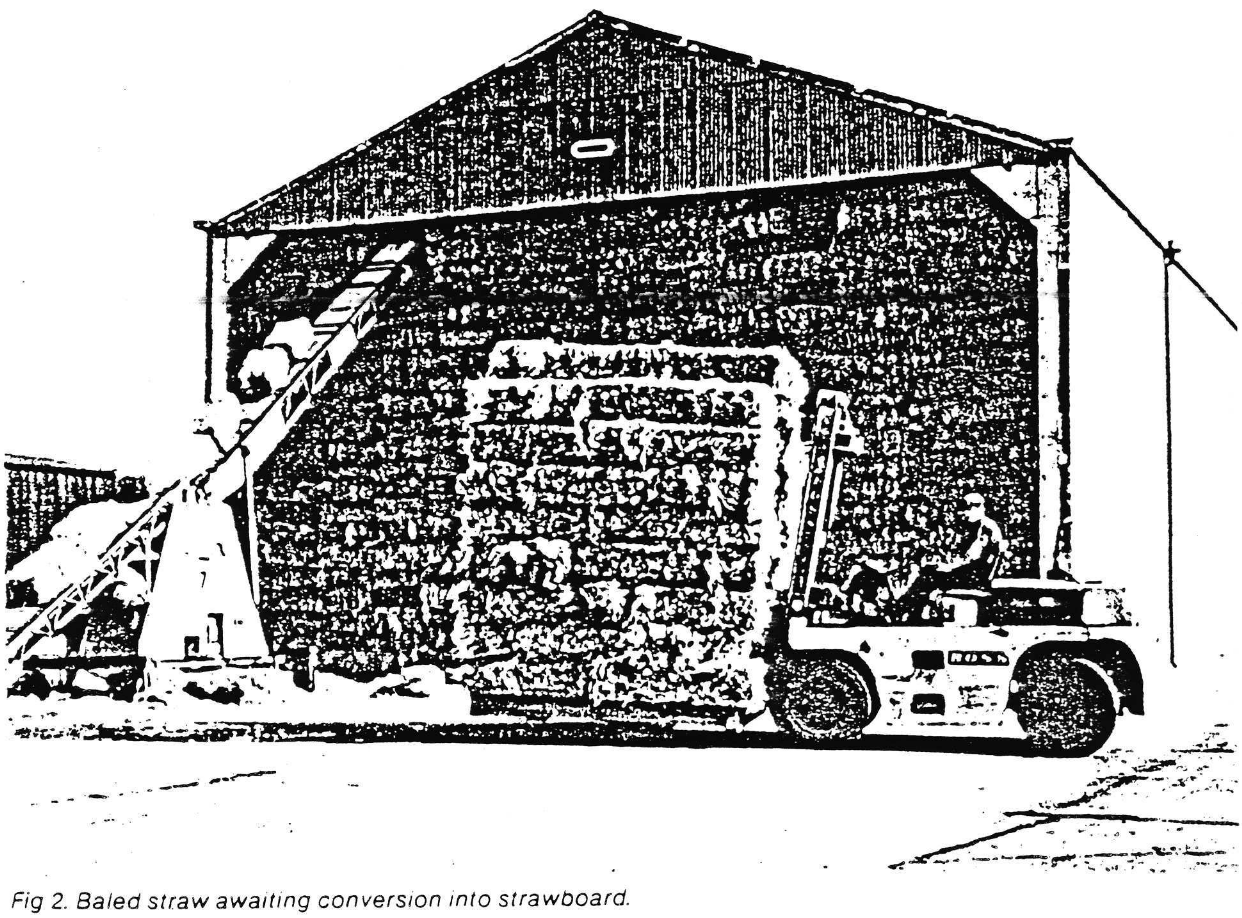


Fig 2. Baled straw awaiting conversion into strawboard.

Fig. 3

Utilities Consumption:

1. Electrical Load

Stramit Machine - heating	97 KW maximum
Stramit Machine - power, including Dust Extraction at Items 1.7.1, 2.1.1 and 3.1.1	66 KW maximum
Allow for following, not included in supply:	
Booster Fan (depending on layout)	25 KW approx.
Ancillary Equipment say	50 KW approx.

2. Compressed Air

Maximum Pressure	5.6	Kgf/cm²
	17	m³/hr of free air

3. Dust Extraction 300 m³/0.3 kgf/cm²

Consumption of Utilities per m²

Paper	0.80	kg/m²	- average
Glue	0.50	kg/m²	- as mixed
Straw	20.00	kg/m²	- average
Electricity	2.00	KWh/m²	- average

Consumption of Utilities per 1,000 m²

Paper	800.00	kg	- average
Glue	500.00	kg	- as mixed
Straw	20.00	tonnes	- average
Electricity	2,000.00	KWh	- average

Consumption of Utilities per Shift Year - 150,000 m²

Paper	120.00	tonnes	- average
Glue	75.00	tonnes	- as mixed
Straw	3,000.00	tonnes	- average
Electricity	300,000.00	KWh	- average

Fig. 4

Personnel:

One Shift operation including materials handling

5 men production	= 5
2 men loading/unloading	= 2
3 men conversion shop	= 3
2 men fork lift, glue mix, miscellaneous	= 2
2 men maintenance	= 2
1 Clerk	= 1
1 Manager	= 1
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Two shift operation including materials handling

5 men per shift production x 2	= 10
2 men loading/unloading day only	= 2
3 men conversion shop day only	= 3
2 men fork lift, glue mix, miscellaneous	= 2
2 men maintenance day only	= 2
1 Clerk day only	= 1
1 Manager day only	= 1
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Three Shift operation including materials handling

5 men per shift production x 3	= 15
2 men loading/unloading day only	= 2
3 men conversion shop day only	= 3
2 men fork lift, glue mix, miscellaneous	= 2
2 men maintenance day only	= 2
1 Clerk day only	= 1
1 Manager day only	= 1
	26

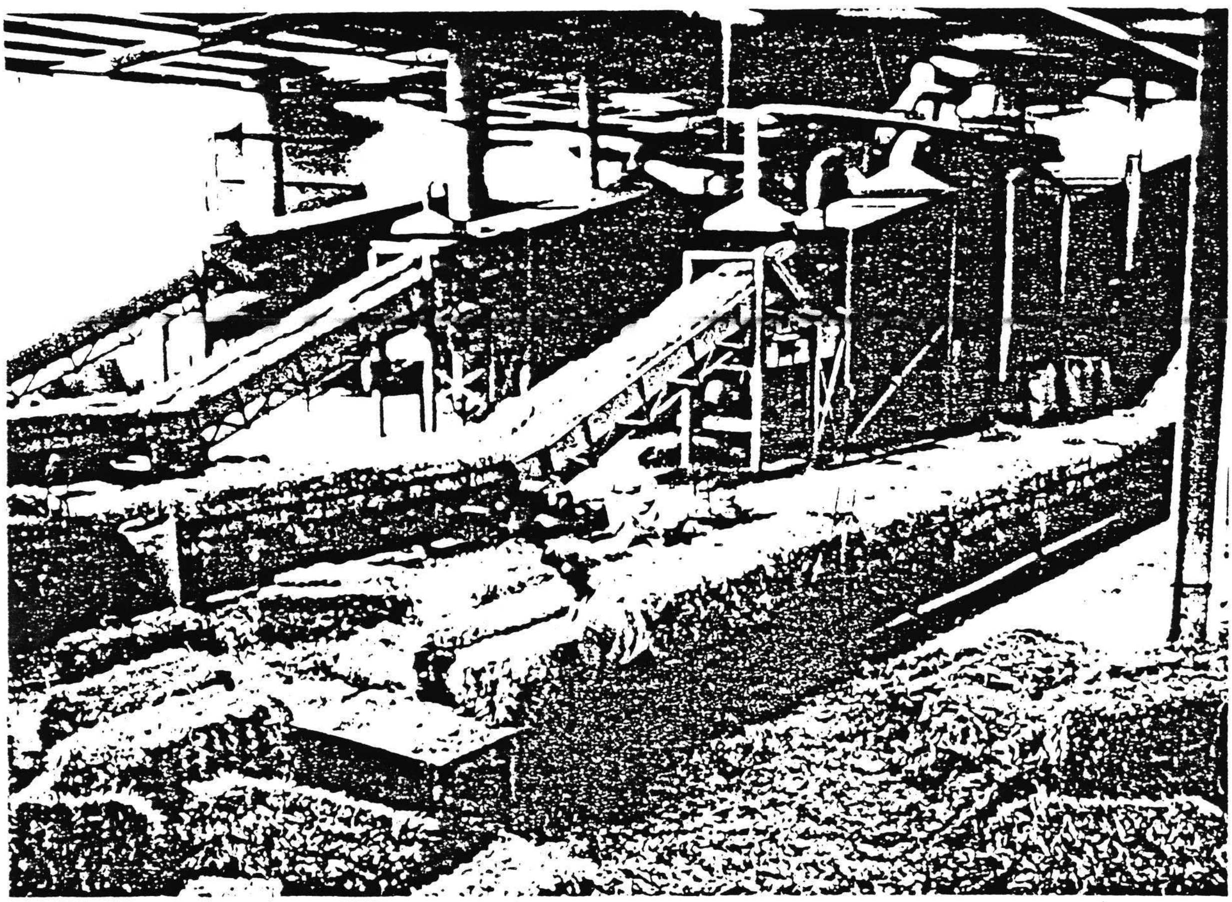

Fig 5. Baled straw passing into strawboard machines.

Physical properties of Stramit strawboard

Today Stramit strawboard is normally made to its own British Standard BS 4046. It is possible to vary the thickness, width, density and surface finish. Typically, the board is made 1200 millimetres wide, 50 millimetres thick and cut in various panel lengths between two and four metres. Optimum British Standard denisty is 19 kilogrammes per square metre at 50 millimetre thickness.

Being tightly compressed, the board offers considerable fire resistance and is used in fire doors and fire resisting walls. Untreated, the board has half-hour fire resistance when tested to British Standard 476, and one hour fire resistance to the same test when treated with a skim coat of plaster.

Sound reduction is approximately thirty decibels averaged over a frequency range between one hundred and three thousand two hundred. The thermal conductivity (K value) is 0.101 Watts per metre per degree centigrade.

With regard to strength, Stramit resists a two ton point load over one hundred square millimetres centrally applied when the board is supported ten millimetres in on its machined edges. The standard Stramit strawboard paper lined type will accept render, plaster, paint and wallpaper.

Uses of strawboard

Strawboards have been used in a very wide range of applications over some thirty years. Principally among these can be mentioned external wall panels, partitions, roof decking, wall lining, shuttering, flooring, ceilings, office screens, mobile homes, duct boards and pallets.

Marketability

Straw, straw products and the use of straw in buildings is highly emotive. The English language abounds in phrases which imply the insubstantiality of straw; man of straw, clutching at straws, straws in the wind.

The Oxford shorter dictionary defines straw when used figuratively as meaning worthless, i.e. when compared to the value of the grain. Every English school child is brought up on the story of the three little pigs and the wolf. The stupidest pig built himself a house of straw which the wolf puffed down in no time and ate the pig. The next most stupid pig built himself a house of sticks. This house proved considerably better than the straw house in resisting the wolf's puffing, but this pig was also eventually consumed. The clever pig who built his house of bricks resisted all the wolf's efforts.

It is hard for a layman to believe, having seen the unprocessed straw burning in the fields in the autumn, that highly compressed straw can be an extremely effective fire resister. Equally, it is probably hard to conceive of a board made from straw having structural properties, having moisture resistance and so on.

Of the three factors technical suitability, commercial viability and designer/user acceptance, only the last is a hurdle.

Thirty years of practical experience has shown the material to be technically sound in a great variety of applications.

The balance sheets of strawboard companies based in widely varying climates, building traditions and economies, testify to the commercial viability of strawboard manufacturing.

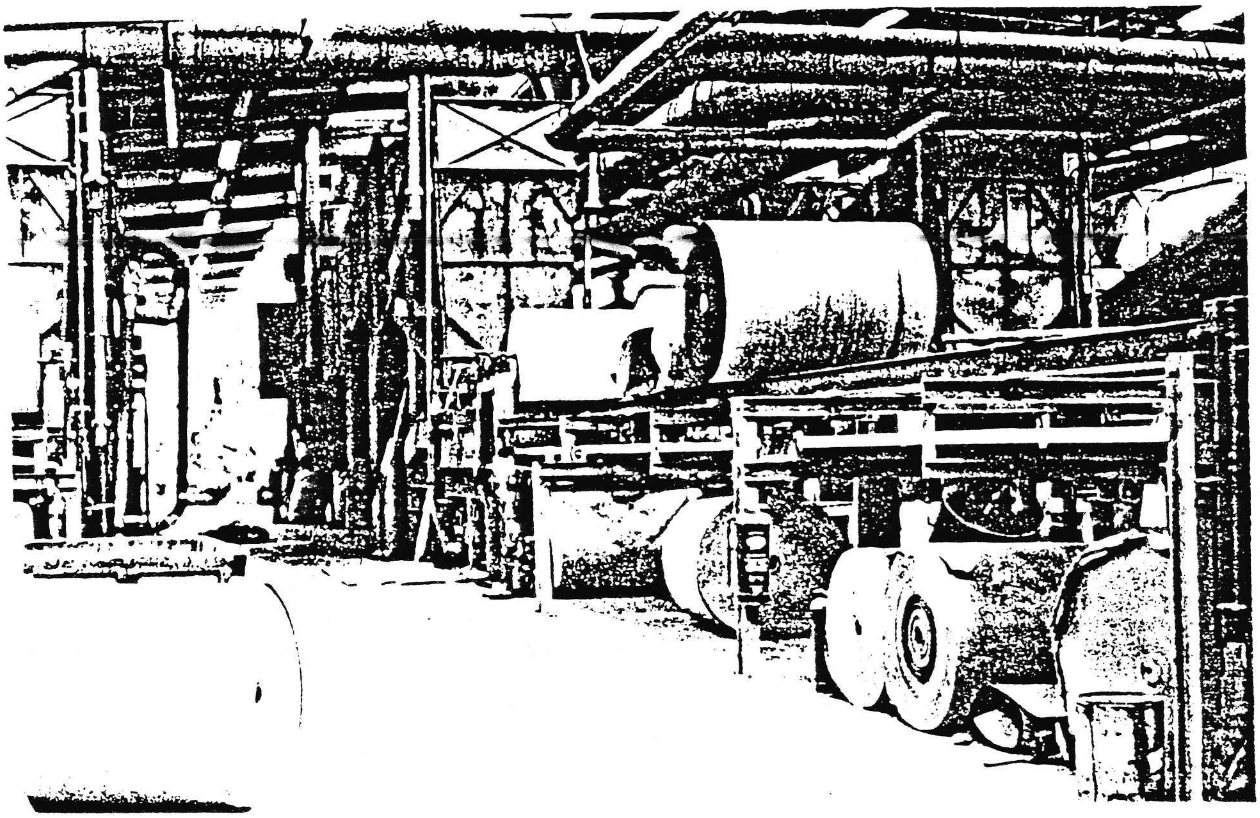

Fig 6. General view of strawboard machine showing hopper in centre of picture, the board being extruded forward towards the right of the picture.

The major task is education; to get designers/users to make an objective investigation. The facts are simple and clear. Millions of square metres of strawboard are already performing functions, most often unknown to the building users, in some of the world's most luxurious and prestigious buildings, as well as in thousands of low-cost prefabricated houses. It is in fact in the field of low-cost housing that the most exciting and potentially massive development is likely to take place.

Fig 7. Installing strawboard lining and partitioning in housing.

Waste ceasing to be waste

Those people concerned with wasting resources can regard successes to be scored when terminology is forced to be changed, i.e. when waste ceases to be waste.

The world famous tennis-court company, En-tout-cas, was founded on waste, or what was once waste. An enterprising businessman in the East Midlands of England – the traditional brick-making area – noticed that a particular brick factory was building up a large pile of bricks. It was a soft red brick and breakages during manufacture were quite heavy. It was discovered that when crushed in a certain way, the resultant material had extremely good properties as a tennis-court dressing – not too dusty in dry weather and good for draining when wet. The tennis-court company built its reputation on this characteristic reddy-brown dressing and flourished – to an extent that demand eventually outstripped supply of the broken bricks and so the bricks had to be made specially, only to be crushed.

Recently, several serious proposals have been put forward for strawboard factories where straw was to be grown for its own sake – because of local shortage of building materials. The straw in the costings was shown to be justified on its own – the cereal being for free so to speak. The so-called waste was shown to rival the material of which it was meant to be a by-product. Such, indeed, can be the services and rewards of those concerned with waste – silk purses from apparent sow's ears.

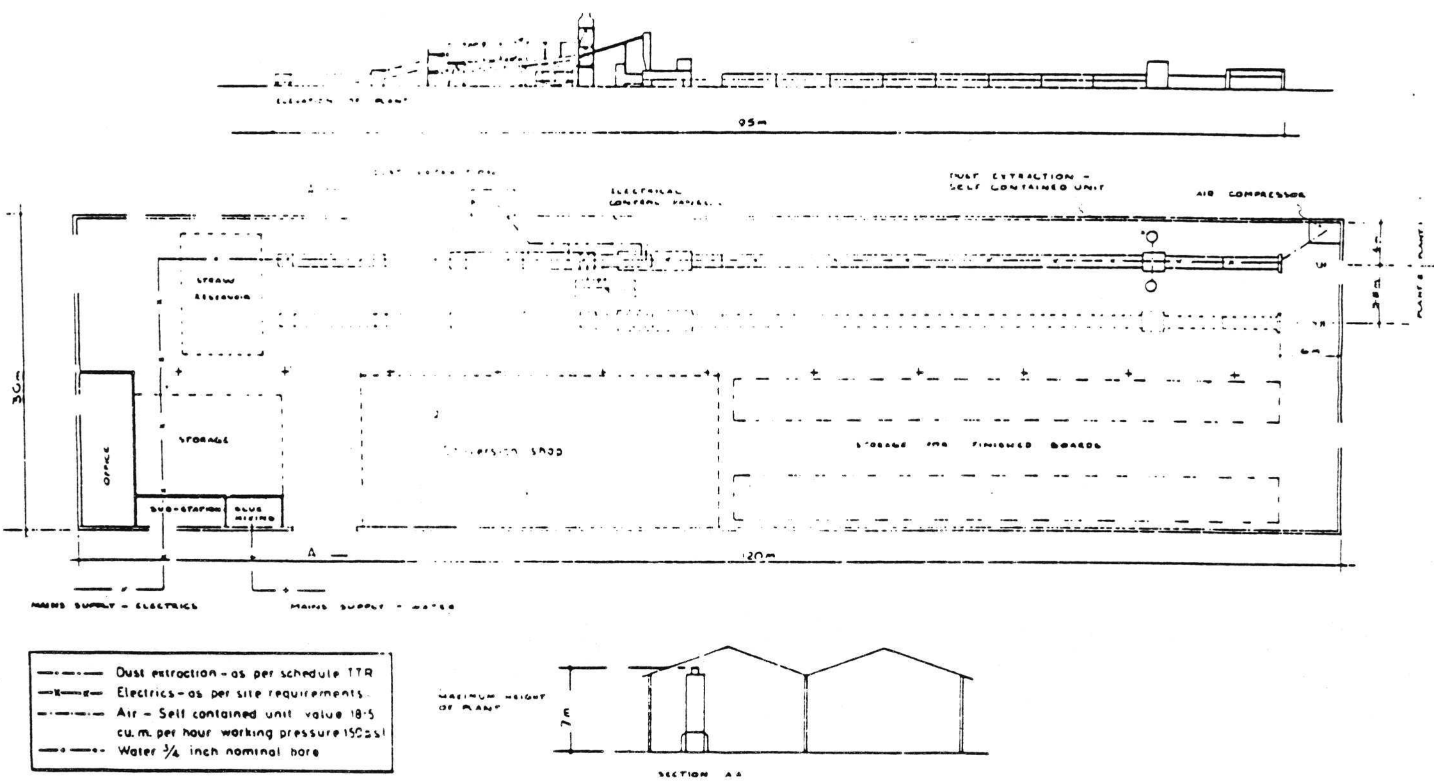

Fig 8. Factory layout. *A Stramit factory: elevation and plans of typical layout.*

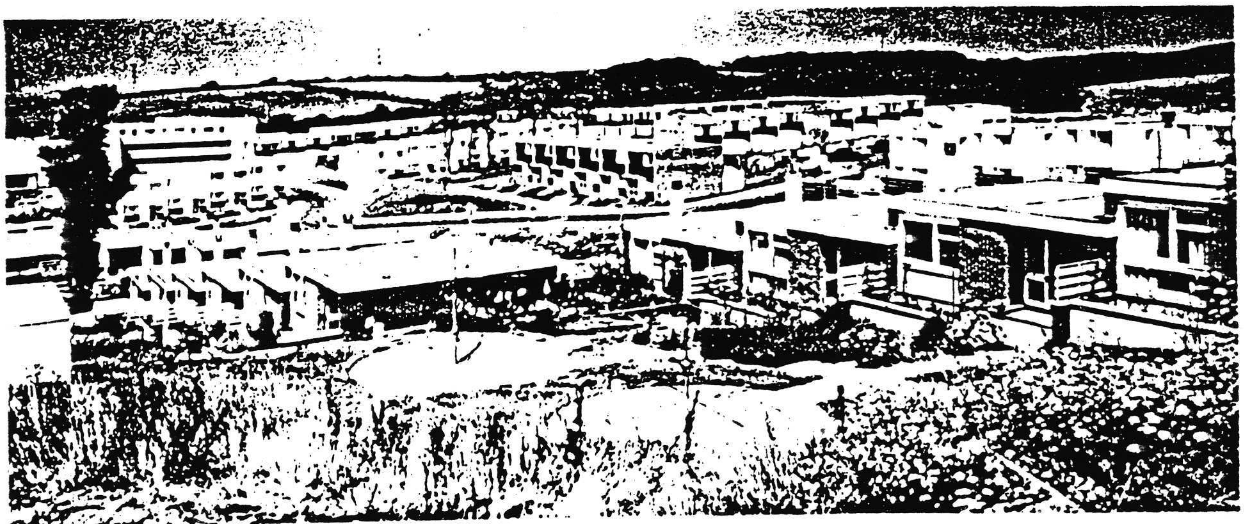

Fig 9. Typical housing development with flat roofs using Stramit for insulation and economy.

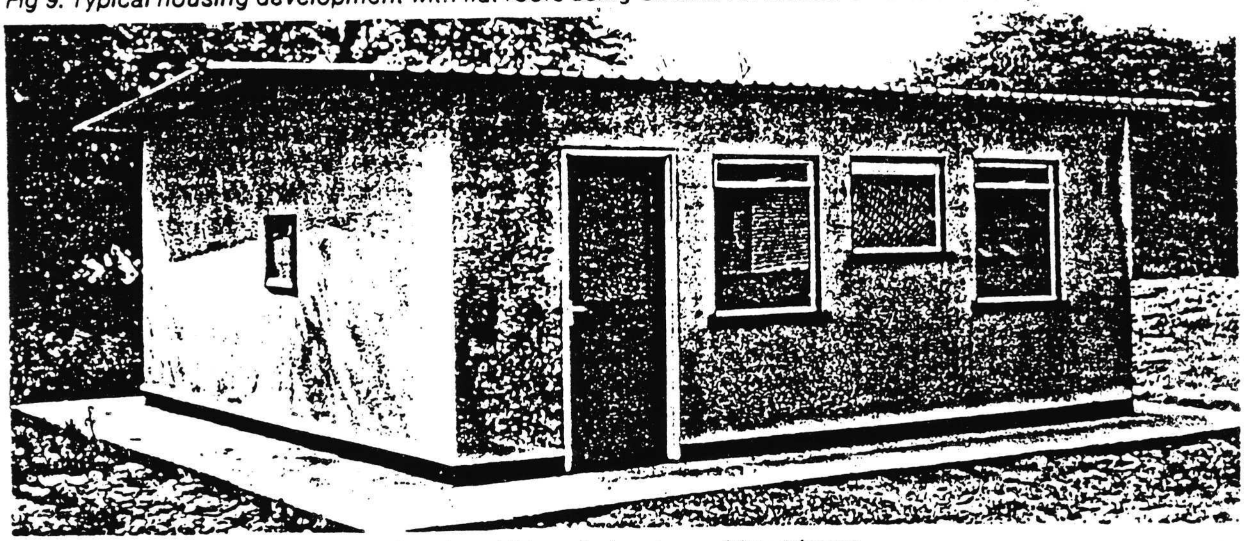

Fig 10. Low cost housing (Brazil). Rendered Stramit structure without frame.

Fig 11. Industrial ceiling (load bearing) and linings.