Part III

Sustainable development and renewables

THE USE OF RENEWABLE RESOURCE BASED MATERIALS FOR TECHNICAL TEXTILES APPLICATIONS

Roshan Shishoo
Shishoo Consulting AB, Svartlavsvägen 18, Askim, Sweden
roshan.shishoo@shishooconsulting.se

ABSTRACT

The renewable resource policies on a global level play an important role for the sustainability of ecosystems. These are also vital for the sustainable growth of the textile industry. Materials from renewable resources, e.g., agro-cellulose fibres are becoming increasingly interesting for many technical textiles applications. Potential markets for agro-fibre based products include absorbents, geotextiles, filters, bio-composites for automotive and building sectors, packaging etc.

In this paper an overview will be given of the state of the art regarding renewable resource-based materials, the relevant processing technologies for the production of bio-composites, and the potential market areas.

Current drawbacks of natural fibres from the point of view of processing technologies and product performance will be discussed. In this context the use of plasma technology as an environment-friendly process in general, and for modifying the surface energies of agro-fibres in particular, will also be discussed. Other developments such as cellulose and starch-based biopolymers for use as matrices or melt fibres in technical textiles and bio-composites will also be discussed.

INTRODUCTION

As shown in Table I, the global production of natural fibres in the year 2002 amounted to over 35 million tons and the natural polymer fibres (man-made cellulosic fibres amounted to nearly 2.7 million tons. The quantities of flax, jute and ramie together constituted one third of the total production of the natural fibres.

In a number of consumer and technical applications of fibres, man-made cellulosic and starch-based fibres are seen to have a good long-term future as they are produced from renewable resources such as wood pulp and corn. For obvious reasons these type of fibres are also fully degradable. Until the introduction of lyocell and poly (lactic acid) or PLA fibres, viscose and cellulose acetate fibres made up the bulk of the natural polymer fibres produced.

Table I. Production statistics of man-made and natural fibres' million tonnes *(2001 and 2002)*

Fibre	2001	2002	% change 01/02
Man-made fibres			
Cellulosic (viscose, lyocell etc)	2.67	2.72	1.6 %
Synthetic (polyester, nylon etc)	31.83	33.80	6.2 %
% of World Total Fibre Production in 2002 : 58 %			
Natural fibres			
Cotton	20.07	20.62	2.8 %
Wool	1.40	1.35	- 3.1 %
Jute	3.35	3.22	- 3.8 %
Flax	7.12	7.20	1.3 %
Ramie	2.00	2.01	0.1 %
Silk	0.88	0.92	4.0 %
% of World Total Fibre production in 2002 : 42 %			

Source: Fiber Organon July 2003

Natural fibres

Natural materials from renewable resources, e.g., agro-cellulose fibres are becoming increasingly interesting for applications other than apparel and household textiles. Because of their ecological advantages over oil-based polymers there are many possible applications for these materials in technical and industrial applications.

The great potential of using agro-fibres in the production of nonwovens, technical textiles and composites offer a new environment-friendly strategy for industrial and technical products. To properly utilise agro-fibres, it is necessary to have a good basic understanding of the property requirements of these types of fibres for various end uses.

Whereas agro-fibres as renewable resources are perceived to have ecological and economical advantages however, the factors such as fibre quality and supply are seen as bottlenecks in the industrial utilization of this fibres in technical textiles applications. Also fibre processing is regarded as complicated both technically and economically as is the relationship between price and performance.

Cellulose is the most abundant of naturally occurring organic compounds, being the chief constituent of the cell walls of higher plants supporting the structure of the plant. It constitutes at least one-third of all vegetable matter in the world. The cellulose content of vegetable matter varies from plant to plant. The botanical classification of the natural fibres is carried out according to part of the plant where they are found:

* bast- or stem fibres (e.g., flax, jute, ramie)
* seed fibres (e.g., cotton, kapok)
* leaf fibres (e.g., sisal, palms)
* fruit fibres (e.g., coconut)

The cell walls of these fibres consists of cellulose and lignin. Values observed for the tensile strength, modulus and elongation of natural fibres depend on their cellulosic content, microfibrillar angle, cell dimension, cell shape and cell arrangement.

The fibre dimensions and some structural, physical and mechanical properties of major types of natural fibres are given in Tables II-IV

Table II. Structural and Mechanical Properties of Some Natural Fibres [1]

Fibre	Cellulose fraction	Angle	Cell length L (mm)	L/D-ratio	Tensile str. (Mpa)	Elong. (%)
Ramie	0.83	7.5	154.0	3500	870	1.2
Hemp	0.78	6.2	23.00	906	690	1.6
Jute	0.61	8.0	2.30	110	550	1.5
Flax	0.71	10.0	20.00	1687	780	2.4
Coir	0.43	45.0	0.75	35	140	15.0

Table III. Dimensions of important natural fibres

Fibre	Fibres			
	Length (mm)		Diameter (mm)	
	Min-Max	Average	Min-Max	Average
Flax	8-69	32	0.008-0.031	0.019
Jute	0.75-6	2.5	0.005-0.025	0.018
Ramie	60-250	120	0.017-0.064	0.040
Hemp	5-55	25	0.013-0.041	0.024
Sisal	0.8-7.5	3	0.007-0.047	0.021
Coir	0.3-1	0.7	0.010-0.024	0.020
Cotton	10-50	25	0.014-0.021	0.019

Table IV. Some physical and mechanical properties of natural fibres

Fibre	Density (g/cm^3)	Tensile strength N/tex)	Breaking extension (%)	Work of rupture (mN/tex)	Initial modulus (N/tex)	Moisture absorption (%)	Effect of heat (100 °C)
Flax	1.54	0.54	3.0	18.0	18.0	7	stable
Jute	1.44	0.31	1.8	17.2	17.2	12	stable
Ramie	1.56	0.59	3.7	14.6	14.6	6	stable
Hemp	1.48	0.47	2.2	21.7	21.7	8	stable
Sisal	1.45	0.30	3.0		15.0	11	stable
Coir	1.24	0.31	1.8		17.2	10	stable
Cotton	1.52	0.19-0.45	5.6-7.1	3.9-7.3	5.9	7-8	stable

The density of natural fibres varies from 0.9 to 1.5 g/cm^3 as compared to glass fibres of 2.5 g/cm^3. Flax, sisal and hemp are most interesting and suitable for technical applications. Flax fibres have already being used in reinforcing applications of polymeric matrices and also for application in the automotive industry.

Flax is a stem plant and the fibre content of the dry stem (straw) is about 25%. Flax fibres have been used in textile fabrics for ages and the use of substitute for glass fibres, asbestos, reinforcement of polymers and papers is very promising. The flax fibre is a strand of cells, its thickness depends upon the number of these cells in any one fibre cross-section, it seems that about 3 to 6 cells or elementary fibres constitute a macro-flax fibre with thickness varying from 10 to 20 μm. Flax is more crystalline than that of cotton having a relatively high modulus and tensile strength make it very suitable for a number of technical applications. Flax also possesses a high heat resistance compared with many natural fibres.

The use of a renewable source based fibres in Europe can only be economically advantageous if fibre prices are low. Therefore only these fibres that are traded in huge quantities in Europe and hence are therefore available at prices considerably lower than the price for glass fibres are of interest. This important consideration means that sisal-, jute-, coconut fibres and flax tow are interesting, because they are available for about one fourth of the price of a glass fibre. However coconut—and jute fibres are not suitable for reinforcing purposes because of their low fibre strength. Hence flax and sisal are more suitable. A comparison of some of the mechanical properties of sisal-, flax-, and E-glass fibre is given in Tables V and VI.

Table V. Mechanical properties of sisal and flax fibre compared to glass fibres [2]

Property	Dimension	Sisal	Flax	E-glass
Tensile strength	MPa	610	900	2300
Modulus of elasticity	Gpa	28	50	73
Elongation	%	2.2	1.8	3.2
Density	g/cm³	1.3	1.5	2.6
Specific strength	Mpa/r	470	600	880
Specific stiffness	Mpa/r	22	33	28

Table VI. Composition of flax—and cotton fibres [3]

	Components with respect to the dry material (%)						
Fibre	Cellulose	Lignin	Waxy subst.	Pectines	Nitrogen	Ash	Pectose
Flax	72.9	4.6	2.1	3.7	0.35	0.86	3.30
Cotton	84.3	1.87	1.12	1.21	0.26	1.00	1.73

NATURAL POLYMER FIBRES

Solvent-spun cellulosic fibres—Lyocell

There are several solvent systems known to be effective for the direct dissolution of cellulose, for example: lithium chloride/dimethyl acetamide; ammonia/amonium thiocyanate. The former Courtaulds company in the UK developed a fibre spinning process based on the use of amine oxide, N-methyl morpholine oxide, to effect the dissolution. This compound is non-toxic and therefore very attractive for the basis of a manufacturing process. Furthermore, the properties of the fibre produced show advantage over cellulosic fibres produced by other processes.

The lyocell spinning process is illustrated in Figure 1. Wood pulp and amine oxide (N-methyl morpholine oxide—NMMO), as a solution in water, are mixed and then passed to a continuous dissolving unit to yield a clear, viscous solution. This can then be extruded into a dilute aqueous solution of the amine oxide, which precipitates the cellulose to fibre. After washing and drying, the fibre is ready for processing. The diluted amine oxide must be purified and is then re-used after removal of excess water. Thus the process utilises materials which are environmentally clean, and recycling of the solvent is an integral part of the process. Waste products are therefore both minimal and non-hazardous, and control is very easily managed.

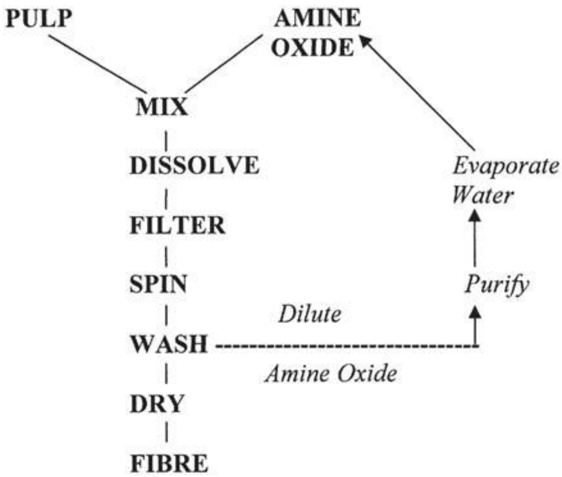


Figure 1 Lyocell fibre process outline

Lyocell fibres initially produced by Courtaulds, UK under the trade name Tencel sold their business to Lenzing, Austria who also manufacture under the trade name Lenzing lyocell. NewCell lyocell fibres are produced by Akzo Nobel.

In Table VII some structural characteristics of viscose fibre are compared with those of solvent-spun fibres. In Table VIII some physical and mechanical properties of viscose fibre are compared with the corresponding properties of Tencel lyocell fibre.

Table VII. Structural comparison of viscose and NMMO fibres

Structural parameters	Viscose (normal)	NMMO (Lyocell)
Cross-section shape	Lobate	Round / Oval
Cross-section morphology	Core/Skin	Homogeneous/ Dense
Crystallinity	Variable	High
Crystallite length	Smaller	Larger
Crystalline width	Larger	Smaller
Crytalline orientation	High (lamella effect)	High
Amorphous orientation	Variable	High

Table VIII. Some properties of lyocell (Tencel) and viscose staple fibres

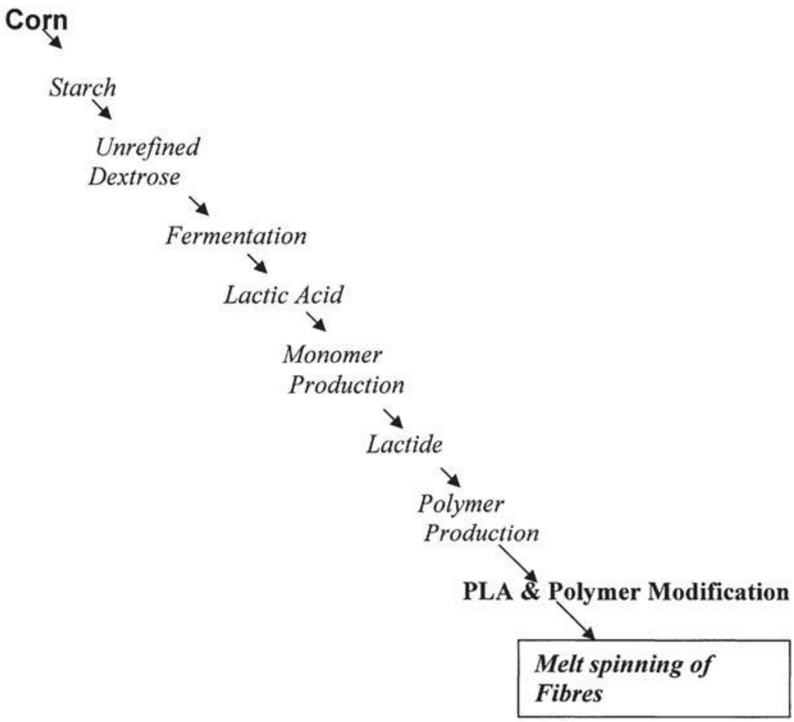
Fibre property	Viscose	Tencel
Titre (dtex)	1.7	1.7
Strength, cond.(cN/tex)	26.0	42.0
Strength, wet (cN/tex)	13.0	38.0
Elongation, cond. (%)	18.5	11.0
Elongation, wet (%)	21.0	13.0

The tenacity of Tencel especially the wet tenacity is higher than that of the other man-made cellulosics. Also of significance is the very high modulus of the lyocell fibre. X-ray studies of the fibre have shown the cellulose crystals to be highly parallel in the longitudinal direction of the fibre. This no doubt contributes significantly to the high tensile strength of the fibre, and it also leads to the propensity for some degree of fibrillation, for example, during abrasion in the wet state.

One can say that lyocell, the new generic fibre type, is a cellulose fibre made by the best available technology to minimise environmental impact by virtue of both being based on the renewable resource and being processed using a non-toxic solvent and solvent extraction built-in process. Lyocell fibre has a higher average molecular weight, orientation and crytallinity than viscose rayon, resulting in high tenacity/modulus. Lyocell retains most of its high strength and resiliency when wet.

Poly(lactic acid) fibre

PLA is an aliphatic polyester where the monomer is lactic acid. The lactic acid can be produced by a fermentation process using lactic acid-forming bacteria. The natural PLA polymer route to fibres and nonwovens is shown in the flow diagram below.



Two types of lactic acid, as two stereo-isomers (L and D-forms), i.e. L-lactic acid and D-lactic acid, can be produced by natural fermentation and from these monomers are obtained L-lactide, meso-lactide and D-lactide. Optical isomers added can allow L/D ratios to be controlled from 99%L to 80%L grades.

The morphology of the polymers and copolymers of lactic acid can be varied from amorphous to crystalline. Copolymerization of e.g. L-lactide with caprolactone, leads to materials with a wide range of properties from glassy to rubber-like. The tensile strength of these copolymers can vary from 0.6 to 48 MPa whereas the elongation varies from 1 to approx. 400% oriented film and fibres have a tensile strength at least 10 times higher.

The physical properties of poly (lactic acid) filament is between those of PET and PA6 (Table IX)

Table IX. Physical properties of PLLA, PET and PA6 filament yarns [4]

Properties	PLLA	PET	PA6
Tensile strength			
(g/dtex)	4.0-5.5	4.0-5.5	4.0-5.5
(Gpa)	0.40-0.55	0.44-0.61	0.36-0.5
Elongation (%)	20-35	20-35	20-35
Young's modulus			
(g/dtex)	60-70	90-120	20-40
(Gpa)	6.0-7.0	10-13	2.7-3.6
Density (g/cm^3)	1.27	1.40	1.15
Crystallinity (%)	83.5	78.6	42.0
Refractional index	1.45	1.58	1.53
Melting temp. (°C)	175	256	222
Crystallizing temp. (°C)	103	170	140
Glass tr. temp. (°C)	58	69	50
Shrinkage in boiling water (%)	8-15	8-15	8-15
Moisture regain (%)	0.6	0.4	4-5

PLA fibres are now being commercially produced by many fibre companies. Some important consumer relevant attributes of PLA fibre are:

- Low moisture absorption & high wicking
- Low flammability and low smoke generation
- High resistance to UV
- Low index of refraction
- Lower specific gravity
- High elastic recovery
- High stain resistance

The above key performance characteristics of PLA fibres makes it very suitable raw material for many applications such as active wear, technical textiles, nonwovens, apparel fashion and home furnishings. PLA fibre can also be used as binder fibre in nonwoven production.

TECHNICAL APPLICATIONS OF NATURAL FIBRES

The price and environmental considerations are two factors which would favour the use of certain natural fibres. However there are some important problems such as uneven quality, continuity and consistency of supply and high moisture sensitivity which need to be solved before natural fibres will be able to replace many synthetic and glass fibres in technical applications. Also there is the need to change the existing negative image of agriculture as a supplier of industrial raw material.

The biggest single application today is the use of natural-fibres in automotive parts. But there are growing markets in other field such as medical, fibre-filled plastics, sport articles, boats etc. The existing and potential technical applications can be classified by use such as geotextiles, filters, sorbents, structural composites, non-structural composites, melded products and packaging.

The successful, commercially-viable production of elementary flax fibres would fulfil the material requirements by the producers of nonwovens, tissue, absorbent material, packaging material and fibre-reinforced plastics. Such a fibre would enable the end users to replace the currently used synthetic fibres and glass fibres. The advantages with natural fibres are that these are ecological, with low density and both low level of toxic emission. The disadvantages are mainly referring to their quality, namely irregular form, moisture sensibility, structural variations and thermal insensitivity to moulding processes. The objectives of major interest are:

- The possibility of developing flax elementary fibres capable of meeting the demands of the industrial partner interested in technical applications.

- Identification and evaluation of processing techniques to produce elementary fibres. The process has to be environmentally and economically sound.

- An overall conclusion regarding commercially viable flax fibre production processes and need of further developments.

Characterization of flax fibres in terms of dimensions and form, and a classification of elementary fibre content from fibre bundles after different defibrillation techniques. The studies were made using a video microscope as well as scanning electron microscope. Fibre damage was studied by scanning electron microscopy. The Video microscopic analyses and visual analyses of samples, were carried out for the determinations the overall result of the fibrillating process. Chemical modifications were made on the elementary fibres to meet the technical specifications, both in processing and of the end product. The main modification concerned wettability which was accomplished by using enzymes and/or wet bleaching processes. Different fibrillating processes resulted in elementary fibres with low wettability.

Modifications of the dispersability of fibres in a wet laid nonwoven process were also necessary. For liquid absorption end-users, the fibres tested in general had low wettability. Modifications were made by an ordinary wet bleaching process. It was also demonstrated that a plasma treatment could also increase the wettability of the fibre specimens.

Four processes of producing elementary flax fibres are:

- Steam explosion technique
- Sulphate process
- Extrusion technique
- Ultra-sound process

It is possible to obtain elementary flax fibres or bundles of fibres having the functional properties listed in specifications. Within the framework of this project the properties were not, however, optimized for the production of various types of end products. There is a need for further research and development in this area. However, two processing techniques were identified to give suitable elementary fibres. One was the sulphate process commonly used to produce cellulose fibres from wood and the other was a steam explosion process as used by IFTH, Lyon. These processes have the potential to be commercialized and there is a strong need for further development in order to optimize industrial treatments for producing elementary flax fibres for technical applications.

Some properties of elementary flax fibre are compared with other types in Table X.

Table X. Comparative properties of some technical fibres [5]

Fibre type	Diameter µm	Density g/cm³	Breaking strength Mpa	Elastic modulus GPa	Breaking strain %
Polyester (high tenacity)	21 - 31	1.38	1100 - 1140	12 - 15	11 - 14
Glass (E-type)	5 - 24	2.6	2400 - 3400	73	3.8
Aramid	13	1.44	2700 - 3150	60 - 90	3.4
Flax (elementary fibre)	11 - 17	1.2	2000	85	2.4

Lyocell in nonwovens applications

The relatively high strength and high modulus of Tencel together with non-creep characteristics give significant advantages to materials for technical use, for example, in substrates for coatings. Tencel fibre can be used in a variety of nonwoven systems which use both dry and wet laid webs and utilize a range of bonding techniques such as latex bonding thermal bonding and hydroentanglement.[6]

Nonwovens produced from Tencel show very high tensile strength, particularly in the wet state, and are significantly stronger than those produced from viscose. This is the case also for both latex-bonded and thermal-bonded webs (Tables XI and XII).

Table XI. Relative strengths of Tencel and viscose latex-bonded nonwovens

	40 g/m2 @ 20 % LATEX			
	Tencel, dry	Tencel, wet	Viscose, dry	Viscose, wet
MD strength	203	153	100	51
CD strength	172	119	100	57

Table XII. Tensile properties of 50/50Tencel/PP, and 50/50 viscose/PP thermally-bonded nonwovens.

		Tensile strength (daN)			
		Machine Direction		Cross Direction	
Bonding		Dry	Wet	Dry	Wet
Plain	Tencel	9.2	10.9	2.6	2.5
	Viscose	7.0	6.5	1.1	1.0
Point	Tencel	7.2	8.2	1.6	1.9
	Viscose	5.2	4.1	0.7	0.7

FIBRE COMPOSITES FROM RENEWABLE RESOURCES

Bio-composites can ideally be defined as any combination of renewable resource-based fibre structures held together by a renewable resource-based matrix. The objective is to combine two or more materials in such a way that a synergism between the components results in a new material with much better properties than the individual components. At present many commercial agro-fibre based composites are made by using non-renewable matrix systems. Bio-composites can be classified in many ways: by their densities, by their uses, by their manufacturing methods, or by other systems. As such these are being classified as low-density/high-density composites, or structural/non-structural composites, or injection moulded/compression moulded products etc.

A structural bio-composite is defined as one that is required to carry a load in use such as in building industry, automotive industry and aerospace industry. Non-structural composites are not intended to carry a load in use and are used for products such as doors, windows, furniture, automotive interior parts etc. In some cases, one type of composite can be used for more than one use. For example, once a fibre web has been made it can be directly used as geotextile, filter, or sorbent, or it can be further processed into a structural or non-structural composite, moulded product, used in packaging or combined with other resources.

The most generally applicable agro-based fibres are flax, cotton, jute, sisal, straw and wood. The main criteria for the selection of plant fibres are price of the fibre, technical and chemical properties, performance and environmental aspects. Special quality criteria for agro-based fibres for use in bio-composites are: adhesive properties reinforcing potential (breaking strength, impact strength), stiffness, wear resistance, brittleness, moisture-related properties (ageing, form stability, swelling), heat stability, purity, resistance to micro-organism, non-odour, resistance to chemicals etc.

Resins and matrices

A wide variety of different synthetic matrices, both thermoplastics and thermosetting resins, which now generally are used for glass fibre reinforced composites have potentials for development of new composite materials with agro-fibre reinforcement and/or fillers. The most frequently applied thermosetting resins are urea formaldehyde, phenol-formaldehyde, melamine-formaldehyde, epoxy and unsaturated polyesters. Thermoplastics used generally are polypropylene, polyethylene, PVC, nylons etc.

In this context, the most interesting developments are those related to thermoplastic biopolymers. Of particular interest are cellulose acetate, cellulose propionate (CAP) and cellulose butyrate(CAB). The successful incorporation of biopolymer-based matrices would be a great step towards the realisation of true bio-composites.

An overview of possible applications of natural fibres in polymer processing is shown in Figure 2 and the technologies to produce fibre-reinforced composites made from natural-fibres and matrices from renewable resources are shown in Figure 3.

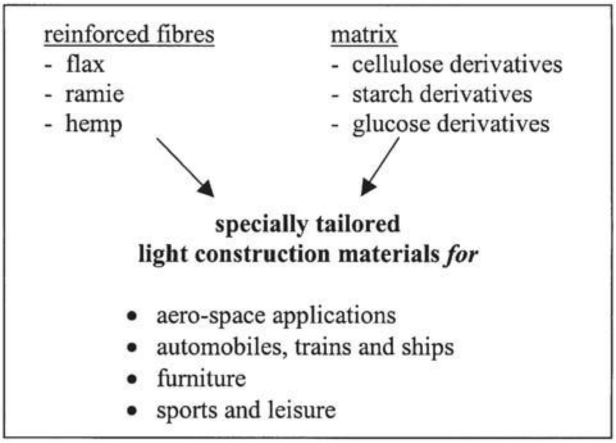


Figure 2 Fibre reinforced composites [7]

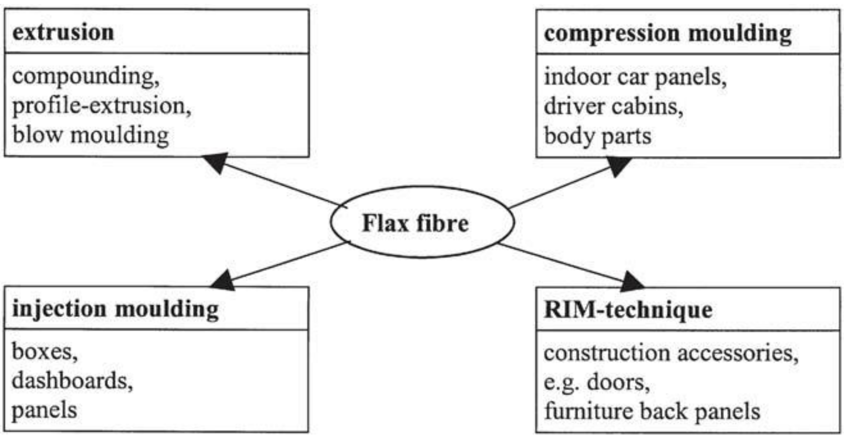


Figure 3 Overview of possible applications of flax in polymer processing [7]

Technology for high-density, thermoplastic composites: High density composites are those in which the thermoplastic component exists in a continuous matrix and the natural cellulose component serves as a reinforcing filler. The processes include *Compounding, Profile Extrusion and Injection Moulding*.

Problems using ligno-cellulose fibres in this area focus on the differences in bulk density of the fibre versus the polymer matrix components and the degree of shear of the compounding equipment, and thus fibre length retention or loss. Additionally fibre-matrix adhesion has to be enhanced

Technology for low-density thermoplastic products: Low matrix content composites can be made in a variety of ways. In their simplest form, the thermoplastic matrix acts much the same way as a thermosetting resin, that is, as a binder to the lignocellulosic component. An alternative way is to use the thermoplastic in the form of a textile fibre. Many synthetic polymer- based binder fibres are now commercially available and some chemical companies are also developing binder fibres based on biopolymers. The meltable textile fibre enables a variety of natural cellulose fibres to be incorporated into low-density,, nonwoven mat. The mat may be a product in itself, or it may be consolidated into a higher density product.

Nonwoven textile-type Composites

In contrast to high-matrix content composites and conventional low-matrix content composites, nonwoven textile type composites typically require long fibrous materials for their manufacture. Nonwoven processes allow and tolerate a wider range of cellulose materials and synthetic fibres depending on the application. After the fibres are dry blended, they are air-laid into a continuous, loosely consolidated mat. The mat then passes through a secondary operation in which the fibres are mechanically entangled or otherwise bonded together. This low density mat may be a product in itself, or the mat may be shaped and compressed in a thermoforming step.

Alternatively the long bast fibres can be used in place of glass fibres in many type of liquid composite moulding systems such as resin transfer moulding (RTM), resin injection moulding (RIM), structural reaction injection moulding (SRIM) and sheet moulding compounds (SMC). All of these techniques include a fibrous mat mixed with a liquid resin, which is polymerised to form a reinforced fibre composite. Agro-fibres are lower in specific gravity, higher in specific strength, lower in costs and less energy intensive to process compared with glass fibres, so they are well suited for these type of technologies.

Moreover, the main drawback with agro-fibres is the lower processing temperature needed because of the potential degradation of lingo-cellulose at elevated temperatures. For this reason the type of thermoplastic matrices or resin that can be incorporated with agro-fibres has earlier been limited to commodity polymers such as polyethylene (PE), polypropylene (PP) and PVC.

The effect of heat on the tensile properties and ageing of some natural fibres are shown in Tables XIII and XIV[8].

Table XIII. Tensile strength (cN/tex) of fibres before and after heat treatment

Fibre	Untreated	Fibres heat at (^oC)			
		150 5 min	150 15 min	220 5 min	220 15 min
Fibres from Flax straw	38.6	44.0	47.5	34.6	34.5
Flax fibre after steam explosion	68.1	63.5	58.6	66.1	53.4
Ramie	61.4	65.5	58.8	42.1	27.8
Cotton	21.9	31.1	28.5	23.2	20.9

Table XIV. Tensile strength of flax and ramie fibres after steam explosion- ageing (cN/tex)

Fibre	Untreated sample	Aged sample	Change in tensile strength (%)
Flax	68.1	56.6	-17
Ramie	61.4	43.0	-30
Cotton*	39.1	41.6	+6

Development of renewable resources based material for automotive interior applications- Green Materials project

The results last year from a national project in Sweden called Green Materials, demonstrated that it is possible to obtain automotive interior panel materials solely made of renewable resources [9]. The work was focused on three different automotive applications; door panels, headliners and sound absorbents and have resulted in a number of small laboratory made materials but also a first lot of prototype materials.

The work has been concentrated on a couple of interesting materials. As renewable matrices there have been investigations based on polylactic acid (PLA), cellulose esters (CAB, CAP) and the aliphatic co-polyester, Eastar-Bio supplied by Eastman Chemicals. In the project fibres of different types of flex, sisal and wood fibres were used.

Investigations have been carried out in various laboratories across Sweden on the matrices, including rheology measurements, surface energy analysis, chemical composition analysis and compatibility studies of the interface matrix/fibre. The fibres too have been investigated in the same way with surface analysis using ESCA, and morphology, surface energy and surface charge measurements. Tests have been made on the derived composite materials namely impact strength, flammability and fogging.

The processes investigated include extrusion to make preforms or compounded materials. A tool to make compression moulded panels has been specified and a number of prototypes have been manufactured. A number of carded preforms, containing a blend of needled punched mats as preforms were manufactured and tested.

The most promising composites are natural fibres combined with PLA and plasticised CAB Most of the evaluations made so far shows promising results. The main drawbacks include odour problems and that the materials tend to be dense and in some cases too brittle.

Surface energies and adhesion

When a bio-composite fails by an interfacial or adhesive type mode, it is presumed that part of the failure arises from the lack of sufficient chemical bonding between fibre and matrix. Strength of composites will therefore improve if one can modify the nature of the component surfaces so that their surface energies are more compatible with one another.

The cellulose molecule is inherently hydrophilic and good wetting of cellulose fibres by any non-polar molten binder fibre or matrix in a bio-composite is essential for the composite manufacturing process. Several different types of functionalized additives have been used to improve the dispersion and the interaction between cellulose—based fibres and polyolefins. In the case of polypropylene/cellulose composites, maleic anhydride (MA)-grafted polypropylene (MAPP) has been reported to significantly improve the bonding between agro-fibre surface and the PP-backbone chains. The maleic anhydride present in the MAPP not only provides polar interactions, but can covalently link to the hydroxyl groups on the cellulose fibre [10].

PLASMA TREATMENT OF FIBRES

Many wet-chemical, surface treatments for adhesion enhancement are becoming increasingly unacceptable because of environmental and safety consideration. Modification of polymer surfaces by plasma treatment, both corona and low-pressure glow discharges, presents many important advantages.

In the plasma treatment of fibres and polymers, energetic particles and photons generated in the plasma interact strongly with the substrate surface, usually via free radical chemistry. Four major effects on surfaces are normally observed, each of which is always present to some degree, although one may be favoured over the others, depending on the substrate and the gas chemistry, the reactor design, and the operating parameters. The four major effects are surface cleaning, ablation or etching, cross-linking of near-surface molecules and modification of surface-chemical structure.

Plasma treatment can be used with great effect to improve the bond strength to polymer-fibre and polymer-polymer combinations, In these cases, the improved properties result from both increased wettability of the treated substrate on polymeric sheet referred by the adhesive and the modification of surface chemistry of the polymer. The changed surface chemistry facilitates reaction of the adhesive with surface species during curing, to form covalent bonds with the plasma-treated interphase. A detailed critical review on plasma surface modification of polymers for improved adhesion has been made by Listen et al [11].

Wettability and adhesion

Modified wettability is one of the most apparent results of plasma treatment and the method used for characterizing the modification is to measure the advancing and receding contact angles against specific liquids. Plasma-produced polar groups increase the surface free energy, γ, of the fibre and decrease the contact angle, θ, which usually correlate with better bonding of adhesives, and θ has often been used as an estimate of bonding quality.

Hydrophobic polymeric surfaces display hysteresis of advancing and receding contact angles (θ_a–θ_r). The lower value of θ_r may depend on the surface roughness, or of polar surface contaminants, or of both. The increasing number of hydrophilic groups as the result of plasma treatment would result in a decrease of (θ_a–θ_r).

Many results published have shown that the plasma treatment conditions necessary to achieve maximum bond strength must be optimized for any given material contribution [12–14]. Also the bonding improvements will depend on the polymer formulation, the type and amount of additives, the adhesive, the cure cycle, the time between plasma treatment and bonding, and of course, the plasma process parameters and the type of plasma gas.

Most commercially-available plasma systems are designed for batch operation. There is a great demand for commercially viable plasma systems able to perform continuous, on-line treatment of fabrics and films for coating/laminating applications. Although some "air-to-air" or "cassette-to cassette", batch-continuous systems have been presented and built for yarn, film and fabric treatment, there are still no satisfactory, cheap and effective on-line systems available [15–18].

Low pressure plasma treatment is essentially a batch process with fabric being treated as it is wound from one batch to another. Technoplasma SA has described their plasma machine KPR-180 [19, 20] and Plasma Ireland has reported about the new plasma unit for on-line atmospheric treatment of textiles and nonwovens as the result of a Brite-Euram project "Plasmatex" [21]. The advantages of industrial plasma treatment over the traditional processing can be summarised below in Table XV [22].

Table XV. Plasma treatment vs. traditional processing for textiles

	Plasma	**Traditional**
Medium	No wet chemistry involved. Treatment by excited gas phase	Water-based
Energy	Electricity - only free electrons heated (<1% of system mass)	Heat - entire system mass temperature raised
Reaction type	Complex; many simultaneous processes	Simple
Reaction locality	Highly surface specific, no effect on bulk properties	Bulk of the material generally affected
Potential for new processes	Great potential, field in state of rapid development	Very low, technology static
Equipment	Experimental, rapid development	Mature, slow evolution
Energy Consumption	Low	High
Water Consumption	Negligible	High
Environmental Pollution	Very low	High

Both low pressure and atmospheric plasma systems are being sold and developed by among others, Europlasma in Belgium and Dow Corning in Ireland. These companies are developing new, powerful, generic and highly manufacturable on-line and batch processes for plasma-based, surface engineering of textile fibres and fabrics, nonwovens, plastic films, cellulose-fibre sheets etc.

CONCLUDING REMARKS

Natural cellulose are selected for price, technical properties, performance and for environmental and agronomical reasons. Process-related criteria in technical applications are exchangeability of materials, processing speed, processing costs and amount of waste production

Drawbacks for some ligno-cellulose fibres in technical textiles applications are inconsistency of quality (within and between batches), mechanical behaviour, moisture related properties, heat stability and durability. The gaps in the research are mainly knowledge of fibre extraction technology, chemical and physical fibre characteristics, possible modification of fibres (bulk and surface), processing techniques of the fibres and bio-composites, and the relation between processing technology and the end product.

On-line, objective testing methods are not available for the determination of relevant fibre characteristics. This obstructs to some extent, the introduction of ligno-cellulose fibres as industrial and technical raw materials. There is need for quick analytical methods for determination of the fibre quality at an early stage in the production chain. This aspect is essential for establishing the product and market potential. For industrial application of agro-fibres in different market outlets, it is vital that these fibres can be produced and supplied with a guarantee of quality.

Application of plant fibres requires adaptation of processing technology and adjustment such as pre-treatments, surface modifications etc. Successful implementation of ligno-cellulose based composites will require adjustment of fibre specification to industrial demands. This includes refining, fibrillation, impregnation, coating, cross-linking, grafting, etc.

New fibre extraction techniques, e.g. steam-explosion and extrusion techniques are promising tools for the production of a uniform quality of fibre raw materials for technical applications.

Opportunities for applications for plant fibre products in building and construction materials are obvious.

There are many different potential markets for composites with polymers reinforced with plant fibres. However, research on the modification of the plant fibres is required to provide the industry with fibres miscellaneous characteristics, so that different demands of composite applications can be met. Modifications of natural fibres regarding moisture sensitivity, chemical resistance, temperature resistance and flammability needs to be carried out. As waste management of the plant fibre composite is expected to be advantageous, it would be of great use to support this arrangement with scientific data.

The problems associated with the use of natural fibres, viz., moisture sensitivity, chemical resistance, heat resistance, flammability etc. have to be dealt with seriously. Since the waste management of the natural fibre-based technical textiles is an important argument, this aspect has to be supported by scientific data.

Technical problems have also to be solved in extrusion processes related to the compounding of ligno-cellulose fibre with polymeric matrices for injection-moulded composites. An important drawback of the use of these types of fibres is the lower processing temperature permissible due to the possibility of thermal degradation and/or the possibility of emissions that could affect the composite properties. The processing temperatures are thus limited to about 200 °C, although it is possible to use higher temperatures for short periods.

The other drawback is the moisture absorption property of the natural fibres and biopolymer matrices. Moisture absorption can result in swelling of the fibres and concerns about the dimensional/form stability of the bio-composite cannot be ignored. It may be difficult to entirely eliminate the absorption of moisture without using some sort of surface barriers on the composite surface. When the problems of dimensional stability and compatibilty between the natural fibres and matrices are solved this could lead to major new markets for agro-based resources and bio-composites.

Potential markets for nonwovens based on plant fibres are: absorbents (hygienic products, sanitary and medical biodegradable nonwovens/disposables); geotextiles (for soil stabilization, drainage, soil erosion control and stimulation of vegetation growth); fillers (for furniture and car seats) and reinforcement (flexible and hard composites). Research topics include adaptation of suitable processing technologies and methods in order to achieve the required fibre and web characteristics.

Potential markets for long plant fibres are reinforcement of paper pulps in general, upgrading of waste paper pulps, and pulp grades for various niche markets. Fibre crops have potential application in areas, other than fibre products, like biomass production for energy generation, as packaging materials, separation media and for chemical and specialities production. Finally cellulose derivatives find many industrial applications as adhesives, binders, films, emulsifiers, thickeners, stabilizers etc.

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SOME PROPERTIES OF KENAF AND KENAF COMBINED WASTE COMPOSITES

W.Y.Wan Ahmad, J.Salleh, M.F.Yahya, M.I.Abdul Kadir, M.I.Misnon
Faculty of Applied Sciences, Universiti Teknologi MARA, 40450 Shah Alam, Selangor Darul Ehsan, Malaysia

ABSTRACT

Kenaf is one of the most promising fibers for composite conversion. In this work, kenaf is being combined with and combing waste or sheared polyester waste and polyester resin as matrix. The comparison of properties are based on tensile strength and flexural strength of 100% resin, 100% kenaf and 50/50 kenaf/cotton combing waste 50/50 kenaf/sheared polyester waste in three types of lay-ups of longitudinal, cross-laid and transverse. The highest results of tensile strength are from 100% longitudinal kenaf and 100% cotton combing waste but the highest results of flexural strength are 50/50 cross-laid lay-ups of composites. The tensile and flexural strength properties are also compared with similar properties on glass composites.

INTRODUCTION

Composite is any combination of two or more resources, in any form, and for any use (1). The normal fibers used for composites are kevlar, carbon and glass. As a result of global environment awareness, many workers of composites turn to low cost, biodegradable materials with improved properties (2). Bio-based resources are renewable, widely distributed, inexpensive, moldable, available locally, anisotropic, non-abrasive, versatile, easily available in many forms, biodegradable, compostible and reactive (3,4,5). One of the main areas of research in composite is in combining natural fibers with thermoplastics (6). Kenaf is one of the biodegradable and bio-based composites. Kenaf (Hibiscus cannabinus L.) is herbaceous warm-season annual fiber crop related to cotton, okra and hibiscus, which can be grown under a wide range of weather conditions (7). Kenaf is a minor textile fiber which has been used as cordage, ropes, basket weaving and alike. However, it seems that now kenaf is discovered as 'versatile' plant which can generate many products such as food for animals, has herbal medicinal properties, and composite from different parts of the plant (barks, cores and leaves). Composite is one of the strong points of kenaf. It can be used to fabricate low-performance composites. The combination of kenaf with cotton combing waste and sheared polyester waste from textile factories will be more notable and 'waste saving' as it will form a value added material in a successful conversion.

MATERIALS AND METHODS

Kenaf is supplied by the Malaysian Agriculture Research and Development Institute (MARDI) and is the main component of the composites for this work. Polyester resin is used as the matrix to bind kenaf and cotton combing waste. On the other hand, cotton combing waste was donated by CNLT (M) Sendirian Berhad, Senawang, Negeri Sembilan Malaysia and sheared polyester waste was taken from Ara Borgstena Sendirian Berhad, Banting, Selangor Darul Ehsan, Malaysia. The sheared polyester waste is from dyed circular knitted automotive fabrics.

Sample Preparation

MARDI carried out the retting process on kenaf and the bast fibers were supplied in strand form. The fibers were then manually combed to straighten and parallelize them. The combed fibers were then cut in approximately six inches length and arranged for composite fabrication in three lay-ups of longitudinal, cross-laid and transverse. These lay-ups of composites were for kenaf only because cotton combing waste and sheared polyester waste are arranged in random form. The layers of web form cotton combing waste and the layers of sheared polyester waste were also cut in six inches square dimension to be in the same dimension as kenaf fibers.

The 100% kenaf

The combed and cut fibers were manually laid up to form layers of fibers at a certain weight according to specified proportions. Figure 1 shows the lay-up of 100% kenaf fibers for cross-laid composite fabrication whereas Figure 2 shows the kenaf fibers lay-up for the longitudinal and transverse forms of composite fabrication.

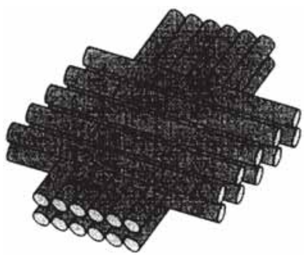

Figure 1: Kenaf Lay-ups for Cross-laid Composite

Figure 2: Kenaf Lay-ups for Longitudinal and Transverse Composite

The 50/50 kenaf combined with other fibers

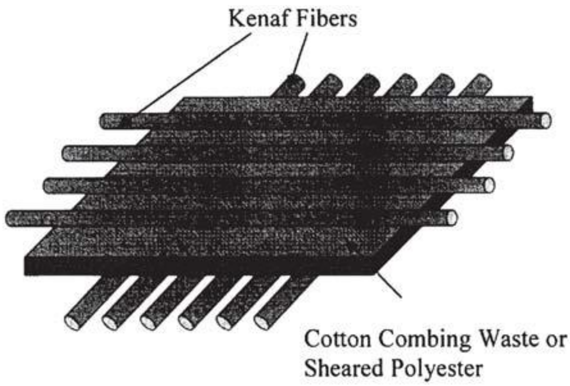

Figure 3: Fibers Lay-ups of 50/50 Combined Kenaf for Cross-laid Composite

The combined samples were prepared by layering cotton combing waste or sheared polyester waste in between layers of kenaf fibers. Figure 3 shows the diagram of the 50/50 kenaf for cross-laid composite. The fiber lay-ups of 50/50 kenaf for longitudinal and transverse composite are shown in Figure 4.

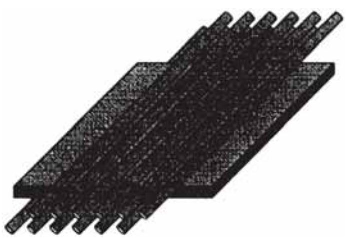

Figure 4: Fiber Lay-ups of 50/50 Combined Kenaf for Longitudinal and Transverse Composite

The fibers which were already arranged to be converted into composites were then applied with polyester resin and pressed in between two aluminum plates (12"×12") using G-clamps and 2 mm spacers (thickness controller) for twelve hours (Figure 5).

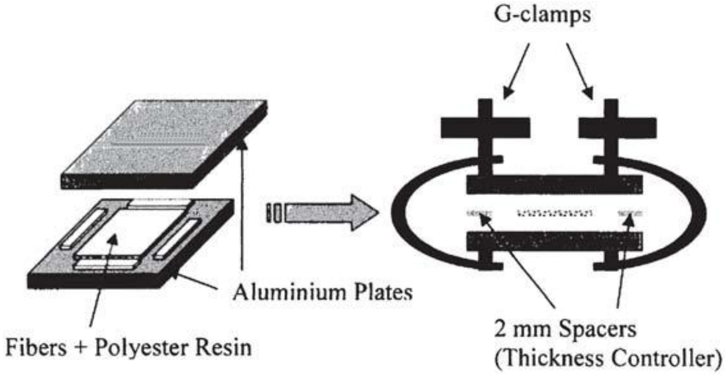

Figure 5: A Typical Composite Fabricating

Mechanical testing

Tensile tests were performed using Testometric Micro—500 testing machine in accordance with Composite Research Advisory Group, CRAG—302 standards. The specimens were tested at the rate of 10 mm per minute. Tensile strength was calculated from load-extension curves. The sample dimension is shown in Figure 6.

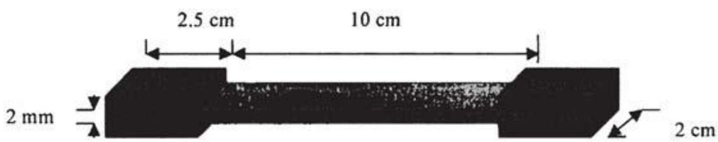

Figure 6: Sample Dimensions for Tensile Test

Fiexural rigidity tests were performed on the same testing machine using the three points bending method as per CRAG—200 standards. The sample dimensions used for this standard testing method are shown in Figure 7.

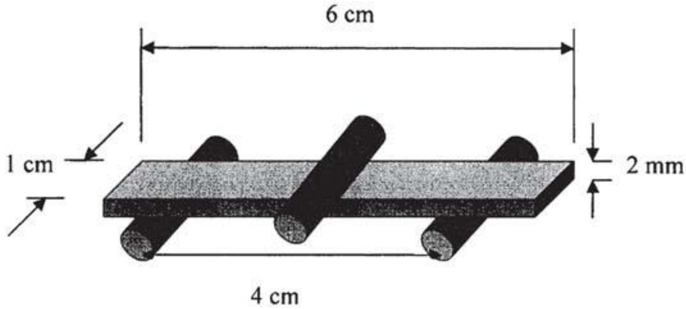

Figure 7: Sample Dimensions for Flexural Test

RESULTS AND DISCUSSION

Table 1 and Figure 8 show the value of tensile strength of composites. In terms of tensile strength, the 100% longitudinal kenaf composite has the highest strength of 90.09 Mpa followed by the 50/50 longitudinal kenaf and cotton combing waste composite(75.37 Mpa). The 100% cotton combing composite has a tensile strength of 70.9 MPa whilst longitudinal kenaf and sheared polyester composite has the strength of 50.14 MPa. The other composites lay-ups have lower values than the 100% polyester resin (matrix). Hence, the composites of higher values than the matrix are considered for future fabrication.

Table 1: Tensile Strength of Composites

Composite Types	Tensile Strength (MPa)
100% Polyester Resin	37.73
100% Cotton Combing Waste (CCW)	70.90
100% Sheared Polyester (SP)	27.93
100% Kenaf (Longitudinal)	90.09
100% Kenaf (Cross-laid)	35.45
100% Kenaf (Transverse)	9.56
50/50 Kenaf/CCW (Longitudinal)	75.37
50/50 Kenaf/CCW (Cross-laid)	35.68
50/50 Kenaf/CCW (Transverse)	33.47
50/50 Kenaf/SP (Longitudinal)	50.14
50/50 Kenaf/SP (Cross-laid)	33.78
50/50 Kenaf/SP (Transverse)	19.49

Similar work on composite as kenaf, cotton combing waste and sheared polyester waste has been carried out on glass fiber but using epoxy resin as matrix. The tensile results are shown in the Table 2. In all cases, the tensile strength of glass fabric is much higher than tensile strength of 100% longitudinal kenaf. The work on polypropylene matrix with non-woven glass composite gave a tensile strength of 100 Mpa (8).

Table 2: Tensile Strength of Glass Composites

Type of fabric	Layers of fabric	Strength (MPa)
Plain weave glass	12 layers (2 mm composite)	149.7 (Warp) 160.9 (Weft)
Satin weave glass	10 layers (2 mm composite	268.7 (Warp) 208.2 (Weft)

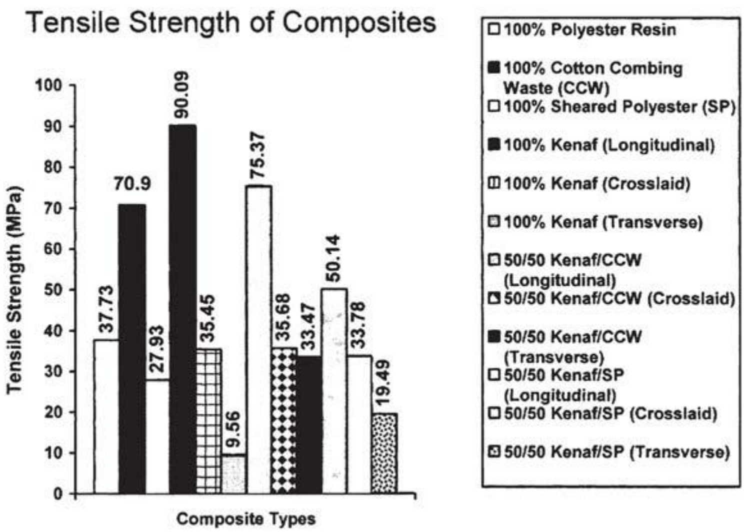

Figure 8: Graphical Presentation of Tensile Strength of Composites

Table 3: Flexural Strength of Composites

Composite Types	Flexural Strength (MPa)
100% Polyester Resin	86.20
100% Cotton Combing Waste (CCW)	126.85
100% Sheared Polyester (SP)	96.79
100% Kenaf (Longitudinal)	125.98
100% Kenaf (Cross-laid)	65.71
100% Kenaf (Transverse)	20.29
50/50 Kenaf/CCW (Longitudinal)	133.07
50/50 Kenaf/CCW (Cross-laid)	136.29
50/50 Kenaf/CCW (Transverse)	35.78
50/50 Kenaf/SP (Longitudinal)	139.50
50/50 Kenaf/SP (Cross-laid)	149.62
50/50 Kenaf/SP (Transverse)	52.00

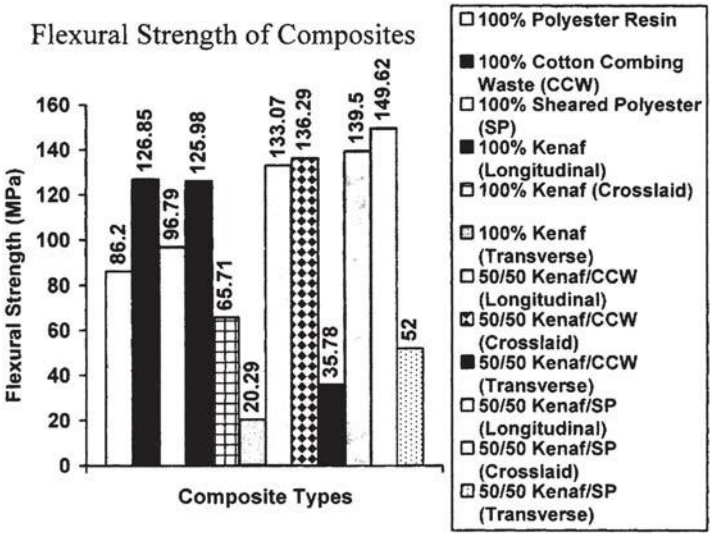

Figure 9: Graphical Presentation of Flexural Strength of Composites

Table 3 and Figure 9 show the flexural strengths of composites. The 100% cotton combing waste and the 100% longitudinal kenaf composites recorded almost the same flexural strength. However, the higher strength comes from 50/50 kenaf longitudinal and cross-laid. In fact 50/50 cross-laid composites have higher strength than 50/50 longitudinal composites for both cotton combing waste and sheared polyester waste. And comparing both of the 50/50 kenaf combined with wastes, the 50/50 kenaf and sheared polyester waste has the highest flexural strength of 149.52 MPa. Other lay-ups for composites show lower flexural strength than the matrix. Comparison with glass composites as in Table 4 indicates that the kenaf combined with cotton combing waste and sheared polyester waste composites has better flexural strength than glass composites.

Table 4: Flexural Strength of Glass Composites

Type of fabric	Layers of fabric	Strength (MPa)
Plain weave glass	12 layers (2 mm composite)	68.8 (Warp) 63.2 (Weft)
Satin weave glass	10 layers (2 mm composite	85.8 (Warp) 70.1 (Weft)

CONCLUSION

It has been indicated that natural fiber materials have the potential to compete with glass fiber in composite materials (9–14). This has been clearly shown in the flexural strength property of kenaf and combined waste composites. The result of kenaf and combined wastes will be higher if the preparation and parallelization of kenaf fiber lay-ups can be improved using machines that can straighten and parallelize the kenaf fibers. It could be at par with glass composites and at the same time the flexural strength may be even much higher than glass composites.

ACKNOWLEDGEMENT

The authors wish to thank MARDI, CNLT (M) Sdn Bhd, Ara Borgstena Sdn Bhd for their cooperation in supplying raw materials and M.K.Yusoh who performed part of the testing.

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TENSILE AND FLEXURAL PROPERTIES OF COMPOSITES MADE FROM SPINNING WASTE

J.Salleh, W.Y.W.Ahmad, M.R.Ahmad, M.F.Yahya, S.A.Ghani and M.I.Misnon
Faculty of Applied Sciences, Universiti Teknologi MARA, Malaysia

ABSTRACT

Spinning especially combed yarn produces considerable waste fibre. These fibres are sold at very low price for fillings. An investigation of converting these wastes to some form of value-added material was successful in forming a composite material made from natural fibre.

Cotton combing noils and blowing waste were fabricated into thin composite boards using polyester resin at room temperature utilising a compression method. Tests on tensile and flexure properties of these composites were evaluated against 100% polyester resin plaques. It was found that composites made from cotton waste were stronger than polyester without the reinforcement. Some possible applications of these composites are thin boards or panels that can be used to replace wood and fibre-board products.

INTRODUCTION

Cotton is the most widely used natural fibre in the world. The demand for cotton has always been strong and the trends over the years, suggesting cotton is holding its own market share while polyester has grown to be by far the most popular man-made fibre. The processing of fibres to yarn and fabric produces considerable waste. The practice of recovering waste is perhaps as old as the art of spinning and weaving. In cotton spinning, short fibres are collected as waste from blowroom to combing. Waste cotton fabrics or even worn-out garments can be garnetted to produce very short fibre. This waste cotton is too short a fibre to be useful for textile applications except as filling material and for cleaning cloths. However, it can be converted into some value-added products such as composites.

Traditional high performance fibre-reinforced plastics use carbon, aramid and glass fibres, as reinforcing fillers. They dominate the aerospace, leisure, automotive, construction and sporting industries. Glass fibres are the most widely used to reinforce plastics due to their low cost (compared to aramid and carbon) and fairly good mechanical properties. However, these fibres have serious drawbacks such as high cost, are non-recyclable, and non-biodegradable, pose high health risks when inhaled, high high energy consumption and high density.

Recently there has been a growing trend of making completely new types of composites by combining different resources using natural fibres as the base fibre. A bio-based composite can be defined as any combination of two or more resources held together by some types of mastic or matrix system[1]. Normally for a composite, the fibres will act as reinforcing filler material and the matrix will serve as a binder and stiffen the resulting assembly. The objective is to combine two or more materials in such a way that synergy is created between these components and thus will result in a new material that is better than any of the individual component.

Recent global environmental issues and awareness in preservation of natural resources and the need for recycling has led to a renewed interest in using natural fibres for composites. Natural fibres are also in general suitable for use in reinforcing low performance composites. They are claimed to exhibit many advantageous properties such as having low-density material, and yielding relatively lightweight composites with good specific properties and are non-brittle (shatter resistant). Natural fibers are also a highly renewable resource which reduces the dependency on foreign and domestic petroleum oil. There may also be significant socio-economic benefits in terms of rural jobs generation and enhancement of the non-food agriculture economy[2,3]. However, the overall physical properties of those composites are far away from the performance of glass-fibre reinforced composites.

Bledzki and Gassan[4] reported that natural fibers were used as early as 1908 in the fabrication of large quantities of sheets, where paper or cotton was used to reinforce sheets made of phenol-or melamine-formaldehyde resins. Natural fibres like flax, sisal, jute, coir and kenaf have all been proved to be good reinforcement materials in thermoset and thermoplastic matrices[5–13]. Many applications of natural fibre composites have already been established in low performance materials. Some common examples are panels for automotive and buildings, pipes and packaging materials[4]. However, many challenges exist in identifying market segments, determining performance requirements, selecting resins, and optimizing manufacturing properties.

Many papers have been published about the effect of chemical treatments on composite properties[2,7,11–14]. Typical and relatively simple treatments, such as an alkali and silane treatments, have proved their usefulness. Work on thermoplastic matrices such as polypropylene and polyethylene[7–8,13,14] showed improvement in composite properties. However, work using thermosets[15–18], especially the epoxides have shown some contradictory findings regarding the influence of coupling agents. More studies on suitable coupling agents are needed.

Waste fibres from textile processing activities can be a source of reinforcement filler for composites. Even in these days of increased environmental awareness, millions of tonnes of waste products from textiles are landfilled each year. Therefore the abundance of these fibers has created the need to develop alternative recycling avenues. One such alternative is their possible conversion to some value-added products. In this project, the suitability of cotton waste as a raw material for the production of composite panel products has been determined. Cotton waste from spinning mills (blowing and combing waste) was processed to form composites using polyester as matrix. Tensile and flexural properties of the composites were assessed.

EXPERIMENTAL

Materials

Blowing wastes from a cotton spinning mill were processed into a continuous fleece of fibres using a scutcher. The sheet of fibres was separated by inserting paper into each layer. Combing noils were also collected from a Cherry-Hara combing machine. At first the noils were randomly packed together and it was found that it caused uneven layers of fibre web during lay-up. Subsequently, the noils were collected in a more systematic manner where each layer was separated by paper. The types of fibre-reinforced composites fabricated from cotton waste were: 100% comb noils (PCN), comb noils+ silane treatment (PCN-S), 100% blowroom waste (PBW), blowroom waste+comb noils 1:1 (PCNBW).

Composites manufacture

Waste fibre fleeces of 150 mm×150 mm were evenly arranged on an aluminum plate measuring 300 mm×300 mm. Several trials were conducted to find the suitable number of layers needed to fabricate into a 2 mm thick composites. These laminates were then pressed between a pair of aluminum plates and were left under pressure for 24 hours in order to pack the fibres together.

Composite sheets were manufactured by impregnating each fibre laminate with polyester resin and 2% methyl ethyl ketone hardener. A 40:60 ratio of fibre to resin was prepared. Air bubbles were removed carefully by squeezing with a steel roller. The impregnated laminate was then compressed under a pair of aluminum plates as shown in Figure 1. A spacer of 2 mm thickness was inserted between the plates. The assembly was left for 24 hours to cure.

Chemical treatment of fibres using a silane agent was undertaken by wetting the combing noils with a 5% w/w silane solution. Excess solution was squeezed using a padding mangle and the treated sheet was dried in an oven at 80°C. The dried comb noils laminates were then processed into composites in the same manner above. For comparison purposes, a 100% polyester plate of similar dimension was also made using a mould.

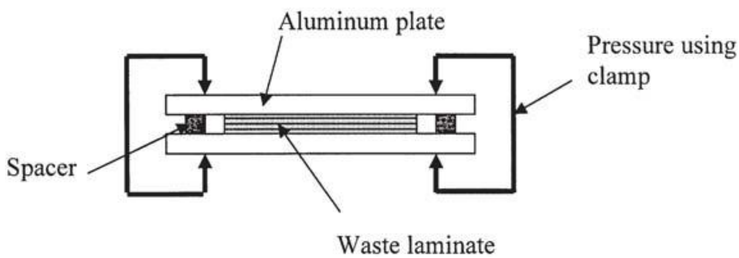

Figure 1: The Assembly for Composite Manufacture

Test methods

Tensile tests were conducted using a Testometric 500 tensile tester according to the CRAG (Composite Research Advisory Group) test method 302. Each end of the specimen was tabbed with the same material using epoxy adhesive to avoid damage at the grips. The width and gauge length were 20 mm and 100 mm respectively and all tests were carried out at a crosshead speed of 10 mm min^{-1}.

Flexural tests were conducted on the same machine using a three-point bending test in accordance to the CRAG 200 test method. The span to thickness ratio should be high enough to produce bending failures. The top and bottom rollers were 10 mm in diameter and the span length was 40 mm. The specimen dimension was 60×10×2 mm and a cross-head speed of 15 mm min^{-1} was used.

RESULTS AND DISCUSSION

Tensile tests

Figure 2 shows a comparison of the measured tensile strength of cotton waste composites. Composites made from combed noils displayed the highest tensile strength (71 MPa) while the polyester resin plate without any fibre reinforcement showed the lowest (38 MPa). In fact, all composites with fibre reinforcement showed higher values than polyester plate. It is evident that cotton waste reinforcement contributes to the tensile strength of composite materials. On average, the fibre volume fraction for waste cotton composites was about 52% except comb noils+blowing waste which recorded only 46%.

It is also apparent from Figure 2 that the longer the waste fibre, the higher will be the tensile strength. Comb noils composites, which consist of longer fibres than blowing waste, show higher strength. However, the experiment with silane shows that the strength is weaker. Although silane is said to improve the properties of glass/epoxy and bio-based thermoplastic composites, it seems that this is not the case for polyester resinated composites. As mentioned earlier, works using epoxides have also shown some contradictory findings; hence more studies are needed here.

Breaking strain values which are shown in Figure 3 also exhibit similar results as tensile strengths where comb noils-containing composites record the highest value (up to 8%). However, the strain readings were taken directly from tensile machine print outs without the use of strain gauges, hence the data may not be reliable. Nevertheless, the values maybe used for comparison purposes of this experiment. Thermoset polyester plate is brittle and breaks at only 2.7%. Again it seems that the longer fibres of comb noils could have held together longer before they fail.

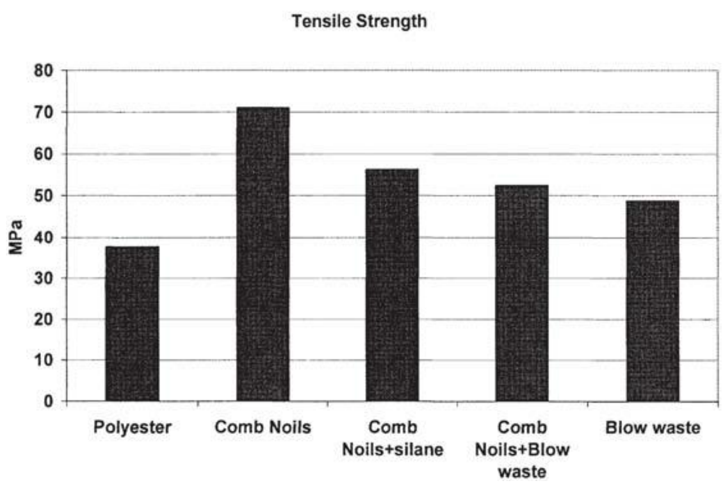

Figure 2: Tensile Strength—Waste Cotton Fibre-reinforced Polyester

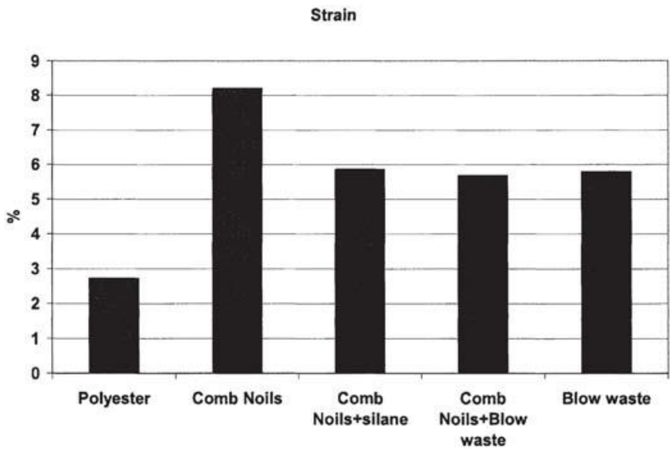

Figure 3: Breaking Strain—Waste Cotton Fibre-reinforced Polyester

Flexural test

Figure 4 shows the result of three-point bend test for cotton waste composites. It should be noted that the flexural test is primarily for material control purposes and does not provide reliable tension and compression data. The composite made from combed noils again displayed superior properties and had the highest flexural strength of 126.4 MPa. Blowing waste composite showed the lowest (83.6 MPa), but the polyester plate also shows somewhat similar results to the blowing waste. Although the mechanisms of failure for tensile and flexural test are different, the trend seems to be similar.

Figure 5 shows the flexural deflection of the composites. The failure mechanism of the fibre-reinforced composites showed the importance of fibre reinforcement of these composites as none of them failed catastrophically. The flexural deflection of untreated cotton waste is almost similar; however the silane-treated composite shows a lower reading and only a little above the polyester plate value. Again, this needs further investigation.

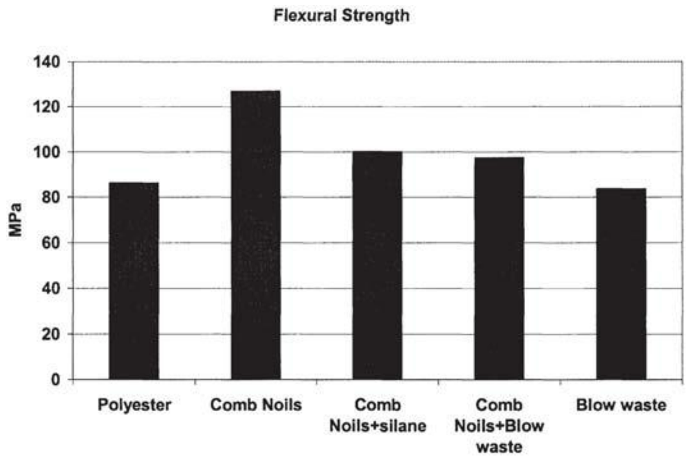

Figure 4: Flexural Strength—Waste Cotton Fibre-reinforced Polyester

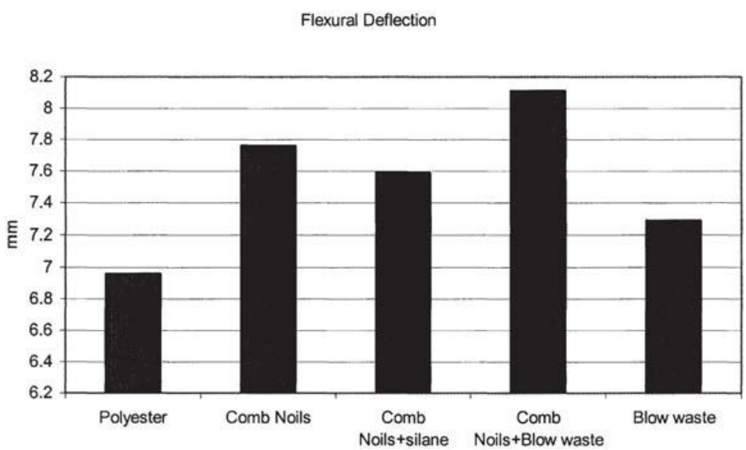

Figure 5: Flexural Deflection—Waste Cotton Fibre-reinforced Polyester

Statistical analysis

An analysis of variance using SPSS 11.5 for Windows was conducted to determine whether any significant difference existed between the treatments. All pairwise multiple comparisons were also made following Post-Hoc test (Duncan). Tables 1 and 2 show the results of these statistical analyses for tensile strength.

From SPSS results, it can be said that comb noils composite is significantly better than all other composites and 100% polyester plate is significantly lower than the others. However, within the experimental error, it can be said that the tensile strength of comb noils+blowing waste and 100% blowing waste composites can be considered equal. It can also be said that the tensile strength of combing noils+blowing waste (1:1) and combing noils+silane treatment composites are similar. On the other hand, composites made from combing noils+silane treatment are significantly better than the 100% blowing waste.

ANOVA on flexural strength shown in Table 3 shows there is significant difference between the samples. Post Hoc (Duncan) test results in Table 4 show that the comb noils composite is significantly higher than the next highest composites which is the comb noils+silane. However, the latter can be considered equal in flexural strength with the comb noils+blowing waste composites. Both of these composites are however statistically higher than composites made from blowing waste and polyester plate, and both of these latter composites are not significantly different.

Table 1: Result of ANOVA on tensile strength.

Comparing	Degrees of Freedom	F	Significance at 0.01	Probability
All Materials	5,20	46.369	Significant	0.000

Table 2: Results of Post-Hoc (Duncan) tests for pairwise comparison

Material	N	Subset for alpha = .05			
		1	2	3	4
P	5	37.5920			
PBW	5		48.7340		
PCNBW	5		52.4260	52.4260	
PCN-S	5			56.2520	
PCN (2mm)	5				71.0060
Sig.		1.000	.159	.145	1.000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 5.000.

Table 3: Result of ANOVA on flexural strength.

Comparing	Degrees of Freedom	F	Significance at 0.01	Probability
All Materials	5,20	27.851	Significant	0.000

CONCLUSIONS

Waste cotton from spinning process can be converted into useful products such as composites. The tensile and flexural properties of composites made from these cotton spinning wastes were studied. It seems that the tensile and flexural strengths of the fibre-reinforced composites increase with length of fibres. Among all the composites tested, those made from comb noils recorded the highest values of both tensile and flexural strength and the polyester plate without fibre reinforcement, the lowest.

Table 4: Results of Post-Hoc for pairwise comparison using Duncan (flexural strength).

Material	N	Subset for alpha = .05		
		1	2	3
PBW	5	83.6300		
P	5	86.1980		
PCNBW	5		97.4060	
PCN-S	5		100.088	
PCN (2mm)	5			126.848
Sig.		.583	.566	1.000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 5.000.

For tensile strength, the order of strongest to weakest composites can be written as follows:
Comb noils>comb noils+silane>comb noils+blowing waste>blowing waste> polyester plate.

The order of flexural strength, strongest to weakest, is as follows:
Comb noils>comb noils+silane, comb noils+blowing waste>blowing waste, polyester plate.

ACKNOWLEDGEMENT

The authors would like to thank IRDC (UiTM) for sponsoring the project, Chempaka Negri Laksmi Spinning Mill for supplying the waste fibres.

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UK TECHNICAL TEXTILES: ISSUES RELATING TO SUSTAINABILITY

Brian McCarthy[1] and Chris Byrne[2]
[1]TechniTex Faraday Partnership, BTTG, Wira House, West Park Ring Road, Leeds, LS16 6QL, UK
[2]Mediatex, Ivy Cottage, Park Road, Combe, Witney, Oxfordshire, OX29 8NA, UK

ABSTRACT

This paper reviews recent trends in the UK Technical Textiles manufacturing sector and sub-sectors over recent years. It reviews the activities of the TechniTex Faraday Partnership during the first three-year period of operation (2000 to 2003). It will give examples of the successful transfer of technology from the UK science base into the marketplace. It will focus on establishing the R&D needs of six key sectors within technical textiles and will address a series of issues relating to sustainability.

INTRODUCTION

The textiles industry is a global industry. Across the world, companies are seeking to expand and grow based on product and process innovation. Increasingly, there are demands to 'get science out of the lab and onto the balance sheet'(1). This issue is being recognised in all economies. 'The Indian Textile sector has to be technology driven to retain its position as a major player in the global textile trade' (2).

It is apparent that compared with other countries, British business is not research intensive, and its record of investment in R&D in recent years has been unimpressive. UK business research is concentrated in a narrow range of industrial sectors (e.g. Pharmaceuticals, biotech, aerospace, etc), and in a small number of large companies (e.g. GlaxoSmithKline, BAE Systems, Rolls-Royce, BT). All this helps to explain the productivity gap between the UK and other comparable economies. However, there are reasons to be optimistic. Britain's relatively strong and stable economic performance in recent years will improve the climate for business investment of all kinds. Public spending on science is increasing significantly in real terms, and the UK's science base remains strong by international standards, whether measured by the quality or the productivity of its output. The UK R&D tax credit provides an important new incentive for business investment (1).

In addition, there has been a marked culture change in the UK's universities over the past decade with increasing attention paid to spin-out companies. Most of them are actively seeking to play a broader role in the regional and national economy. The quality of their research in science and technology continues to compare well against most international benchmarks. The UK has 90 Universities, 115 Institutions and 56 Colleges of Higher Education with a combined income of £13.5 billion.

THE UK TECHNICAL TEXTILES SECTOR

Business is changing too. Growing numbers of science-based companies are developing across the country, often clustered around a university base. New networks are being created to bring business people and academics together, often for the first time. The

UK has real strengths in the creative industries, which are also learning to co-operate with university departments of all kinds (3). However, it is claimed that only 16% of UK businesses engage with the science base.

The UK technical textiles sector numbers some 350 manufacturing companies directly manufacturing fibres, yarns and fabrics with over 700 companies in the broader supply chain. Other textile manufacturers produce some element of technical textiles in their overall output.

FARADAY PARTNERSHIPS

Faraday Partnerships, a flagship UK government initiative, aim to encourage businesses to work with the science base. These alliances include businesses, universities, Research and Technology Organisations, professional institutions and trade associations. There are now 24 partnerships involving over 60 university departments, 27 independent research organisations, 25 intermediary organisations and more than 2,000 businesses—large and small. The core activities of the partnerships include the two-way exchange of information between business and universities, collaborative R&D and development projects, technological and dissemination events. Each Faraday receives £1 million from the UK Research Councils to establish core research activities in their own field or sector. The Lambert Review concluded that Faraday Partnerships can play a valuable role as an intermediary between business and universities.

A Faraday Partnership promotes improved interaction between the UK science, engineering and technology base and industry. A Faraday Partnership is an alliance of organisations and institutions, which can include Research and Technology Organisations, universities, professional institutions, trade associations and firms, dedicated to the improvement of the competitiveness of UK Industry through the research, development, transfer and exploitation of new and improved science and technology.

Faraday Partnerships (2) are dedicated to improving the competitiveness of UK industry through more effective interaction between the science and technology base and industry. Effective interaction requires the identification of industry needs and the subsequent synthesis of the knowledge and experience of those who can satisfy these needs. Crucially, each Faraday Partnership employs a number of technology translators—people with broad experience of knowledge transfer—who can facilitate projects between Partnership members. Established Faraday Partnerships are widely recognised for their technological expertise and understanding of industry's needs. Industry therefore benefits from interactions with the relevant Faraday Partnership(s) and participation in their activities when embarking on new product and process development.

Faraday Partnerships aim to:

- be widely recognised for their technical expertise and be UK industry's first choice for help with new product and process development.
- provide better ways of exploiting R&D to create new products and processes and provide more effective and coherent uptake of the various support mechanisms available (and provide of human and financial resources) e.g. TCS/KTP, LINK, CASE awards, SMART, International Technology Service, Eureka, European Union Framework Programmes.
- link many different organisations, each with a part to play in delivering the Partnership objectives.

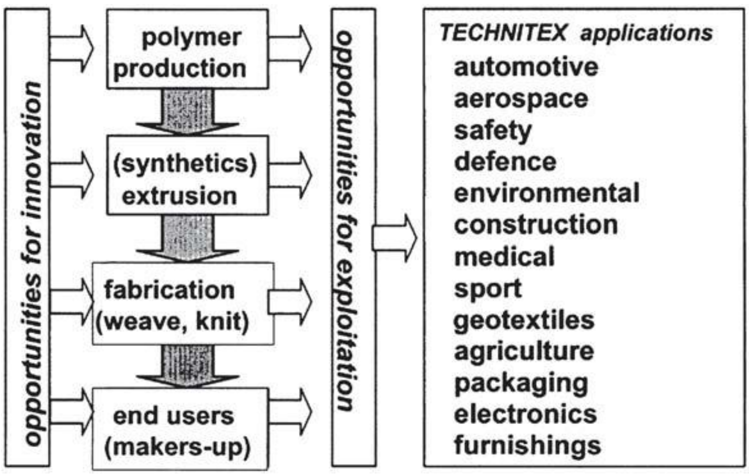
- deliver the four ‘Faraday Principles’.

The Faraday Principles:

1. Promoting active flows of people, science, industrial technology and innovative business concepts to and from the science & engineering base and industry.
2. Promoting the partnership ethic in industrially relevant research organisations, business and the innovation knowledge base.
3. Promoting core research that will underpin business opportunities.
4. Promoting business-relevant post-graduate training, leading to life-long learning.

TechniTex is a partnership between BTTG, Heriot-Watt University, the University of Leeds and UMIST (3). The clear focus is the UK Technical Textiles sector. The Chairman of TechniTex is Lord Simon Haskel—Past World President of the Textile Institute and Deputy Speaker of the House of Lords.

The UK technical textiles industry sector and market has always been difficult to define, especially for the purpose of collecting useful and consistent statistics.



Textile fibres, yarns and fabrics are used in a wide range of downstream applications such as reinforcement, protection, insulation, absorbency, filtration etc. and there are continual definitional problems about exactly where the boundaries of the textile industry and its activities lie. For example, the coating of PVC or rubber onto a textile fabric is, by convention, considered to be a textile process whereas the manufacture of a tyre, also involving the bonding of textile reinforcement to rubber, is normally not so regarded. Numerous other ‘grey’ areas exist. Many fabricators and processors of technical textiles (and, indeed, some manufacturers of new-generation textile materials such as nonwovens) are reluctant to recognise themselves as part of ‘the textile industry’ at all.

Problems also arise with regard to the increasing overlap between technical textiles and traditional consumer applications (clothing, interior textiles etc.). Protective clothing technologies and functions have diffused into many areas of performance, sport and leisure clothing while most furnishing, household and decorative textiles now have strong technical functions, especially fire retardency (4).

Overall demand for technical textiles in the UK appears to have peaked at around £1.5 billion in 1996 after a number of years of strong growth in the mid-1990s. Since then, and even more markedly since 2000, there appears to have been an accelerating decline in UK total output and consumption, primarily due to be a long term movement of downstream manufacturing operations to off-shore locations. Total usage of technical and industrial textiles in the UK had fallen to around £1.2 billion by the year 2002. However, from 1998 to 2004 exports rose by 12%.

However, these bare statistics conceal some very different trends, with continuing decline in some older, more traditional areas of 'industrial' textiles but exciting growth possibilities in newer, more technical products and application areas.

Mature product areas particularly under threat include:

- sewing thread
- 'canvas goods', including tarpaulins, sacks, bags etc
- tyre cord
- waddings, cotton wool etc.
- coated fabrics

The coated fabric industry appears particularly vulnerable to future decline, even though coaters have made valiant efforts to increase exports over recent years. There is very little slack left for them to take up.

Undoubtedly, the fastest growing area of technical textiles is the nonwovens sector although, UK nonwovens manufacturers are failing to take full advantage of the opportunities available. The UK has undoubted strengths at the heavier end of market, including needlefelt and stitchbonded fabrics but in other areas there is high import penetration by a highly globalised industry.

Although trends in the coated fabric and made-up goods sectors may have an increasing knock-on impact on the UK weaving sector, there are still some encouraging signs here. The weaving of high tenacity yarns and glass yarns are both showing signs of growth as well as enjoying healthy balances of trade. Glass weaving is a particularly strong area, presumably driven by demand from the composites and asbestos replacement markets.

Other areas where UK manufacturers are managing to maintain their position in reasonably stable markets are:

- mechanical rubber goods
- rope, twine and netting
- papermaking felts.

However, UK nonwovens manufacturers are failing to take advantage of opportunities in this rapidly growing market. Other than some UK strengths at the heavier end of nonwovens, including needlefelt and stitchbonded fabrics, the outlook is one of increasing import penetration by a highly globalised industry.

Overall, the UK has a net trade deficit of about £0.15 (12% of net supply) in technical textiles. However, this disguises the fact that the UK exports some 68% of its output and imports 67% of its requirements. The technical textile market is a highly segmented one with large volumes of specialised products being traded in both directions.

EXAMPLES OF SUCCESSFUL INNOVATION AND EXPLOITATION

The Cancer test bra—being developed by Dr Wei Wang (Biomedical Engineering Unit, De MontFort University, UK). The bra works by detecting abnormal breast cells with electrical currents—a non-invasive process. The bra is being tested by the Tianjin Virtual Engineering Co. in China.

The introduction of flight socks for the prevention of embolism during long haul flights by SSL plc of Oldham, UK—(4)

Electrospinning of carbon nanotubes—Prof. Alan Windle—University of Cambridge, UK

Praybourne Products, UK have incorporated electro-luminescent cables into PPE workwear to provide active protection.

Laser technology applied to textiles—Dr Martin Sharp—University of Liverpool, UK

Novel medical textile implants—Mr Julian Ellis—Ellis Developments, UK Each emerging technology has associated sustainability issues.

SUSTAINABILITY ISSUES AFFECTING THE SECTOR

As high-volume traditional textile manufacturing continues to move towards China and the Pacific Rim, developed countries—Japan, Koreas, Germany, Italy, etc.—are investigating and investing in the technical textiles sector.

In traditional textiles proactive strategies have been adopted by the textiles sector based on eco-efficiency, cleaner technologies and product stewardship. For example, UK-based Interface Fabrics have adopted the following approach:

1. Eliminate Waste—The first step to sustainability: eliminating waste and the concept of waste, not just incrementally reducing it.
2. Benign Emissions—Eliminating molecular waste emitted with negative or toxic impact on our natural systems.
3. Renewable Energy—Reducing the energy used by our processes while replacing non-renewable sources with sustainable ones.
4. Closing the Loop—Redesigning our processes and products to create cyclical material flows.
5. Resource Efficient Transportation—Exploring methods to reduce the movement of molecules (products and people) in favour of moving information via plant location, logistics, information technology, video-conferencing, e-mail and telecommuting.
6. Sensitivity Hook-up—Creating a community within and around Interface that understands the functioning of natural systems and our impact on them.
7. Redesign Commerce—Redefining commerce to focus on the delivery of service and value instead of the delivery of material; engaging external organisations to create policies and market incentives that encourage sustainable practices.

The sector will be faced with future drivers and trends including (5):

- New multi-fibre agreement in 2005
- SA8000 and social accountability
- EMAS regulation and supply chain management
- Green purchasing networks

- Retailing supply chain management
- Financial rating and institutional investors
- GRI reporting initiative
- Indicators and benchmarking networks
- Consumer boycott and sportswear

The UK textile banks in particular—charity clothes to developing countries—have serious issues with low value waste and are heavily reliant on landfill.

Technical textiles raise particular issues:

- The fibre is selected to provide performance rather than aesthetics—it may be over-engineered to provide guaranteed functionality
- The technical textile may be a sub-component of a larger assembled unit with potential recycling implications
- Performance and functional fabrics are increasingly made of fibre blends—again with recovery and recycling implications
- At the lower end of technical textiles (e.g. sacks, etc.) with cheaper material used in reasonably high volume—there is a need for an environmental impact assessment
- At the higher end some fibres produce great improvements in functionality and performance in use that far outweigh the associated environmental impact

The sector needs to respond to these challenges by greater investment in R&D and innovation. Two areas of particular interest have been identified. The first relates to increasing the service life of products (e.g. personal protective equipment for fire-fighters) by providing novel in service after-care chemical treatments. The second relates to 'smart' tagging of the textile product or sub-component to aid the tracking of the material during its working life and to assist recycling or reprocessing.

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