COMMON FUND FOR COMMODITIES

FAST TRACK Project

Composite Applications using Coir Fibres in Sri Lanka

Final Report

Project Number CFC/FIGHF/18FT

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Summary

This report describes the activities and results that have been achieved within the project "Composite Applications using Coir Fibres in Sri Lanka", a project submitted by the FAO-IGHF, and funded by the Common Fund for Commodities.
The project was carried out within the frame of the CFC corporate contract nr. 02/32 between the CFC and the Delft University of Technology who acts as the 'Project Executing Agency'.
The project was carried out between 1 October 2002 and 1 November 2003 and the research was done at the laboratories of Industrial Technology Institute, Colombo Sri Lanka and the Delft University of Technology, Netherlands.

Manufacturing techniques to create composite components out of coir fibres and polymers were investigated and some simple prototype samples were made. At the end of the project the results were presented and discussed at a workshop, that was held in Colombo.

At the workshop it was explained and demonstrated that with a number of manufacturing technologies composite components can be made from coir fibres and polymers. Vacuum injection is suitable for small batch production of large and complex 3-dimensional forms, while compression forming with thermoplastic prepregs and LFT moulding are suitable for various large series of smaller components. A cost effective method for cleaning and treating the fibres is washing the fibres in a 5% NaOH solution. The vacuum injection process requires compressed (ironing) mats as a semi-finished material. The compression moulding techniques require a pre-impregnation of the mat with a thermoplastic (prepreg). Developing a proper semi-finished material is an essential task for the coir industry. This can be the first step to enter the market of composites and to deliver a commodity with a higher added value.

During the workshop also future strategies were discussed in order to start a co-operation between the Sri Lankan plastics industries and coir fibre industries, and to start developing industrial products made of coir composites. It has been decided that, with the guidance of the Coir Council International, a team of 3 coir companies and 3 plastics companies will be formed to discuss and determine the choice of Technology, Product and Market for Coir composites. This team will form an action plan within a period of 6 months.

Acknowledgement goes to the CFC, without their funding the project was not possible. Also the USAID Competitiveness Initiative is acknowledged, it funded the visit of the ITI researcher to the Netherlands.

1. Introduction

The background of the research that has been carried out is the awareness that the demand of coir and coir products is slowly decreasing and that other profitable markets have to be found for this commodity. The best way to bring the existing coir industry to a higher level is the development of new coir products with higher added value.
One possible technology that could fulfil this goal is the use of coir fibre in composite components. A composite in this respect is a compound between a polymer (such as polyester or PP) and a fibrous material (such as glass, carbon or natural fibres). Composite products have good mechanical properties per unit weight, are durable and their technologies allow the manufacture of complex and large shapes.
It is clear that composite technologies allow the producer to add much more value to his product than the processing and trading of raw material. Not only ready products, but also semi-finished composite material can be a new market with higher added value for the coir industry. Pre-impregnated mats, boards, panels or hybrid yarns are examples of these half products. The development of new and more profitable markets will improve the position of the (mainly poor) people working in the coir industry and increase their welfare.

Other natural fibres such as flax and sisal have already shown that they can be used successfully in composite components in order to realise reduction of weight and cost. Demand for natural fibre based composite originated from automotive industry. Research focussed on locally grown fibres, for instance European automotive industry mainly uses flax and hemp, whereas the Brazilian automotive industry mostly applies locally grown sisal. Using the automotive industry as stepping stone towards other markets, each natural fibre based composites has found other applications, depending on the specific properties of the fibres. Coir based composites, depending on its specific characteristics, could also find a position within the wide scale of applications and products in and outside the automotive industry. Until now little research on coir composites has been carried out, so far only some material characteristics have been studied while research on processing in combination with product development has not been undertaken.

Considering the above, a group of Sri-Lankan industries decided it was time to investigate the possible potentials of coir in composite technologies.
Jafferjee Brothers and Hayleys, two Sri Lankan coir industries and Zylyon a trading and marketing office in Europe contacted the ITI Colombo and the Aerospace department of the TU-Delft, and a cooperative research program was written and submitted to the CFC.
In order to investigate the feasibility of coir composite components the following research tasks were defined in this project;
a) investigate the suitability of coir for a selected number of composite manufacturing technologies,
b) assess the economic possibilities of coir fibres when used in composite technologies,
c) demonstrate the technologies by manufacturing prototypes of marketable products, and
d) informing relevant parties about composite processing technology in Sri Lanka by means of a workshop.

Right at the start of the project it was decided to strengthen the co-operation between ITI and TU-Delft by having an R&D engineer (mr. Chandana Katugaha M.Sc.) from ITI Colombo working for two months in Delft at the laboratory of the University. The benefit for this was mutual, TU-Delft could be informed about coir, coir treatments and the coir infra-structure in Sri Lanka in an optimal way, while on the other hand mr. Katugaha learned more about composite processing technologies which was a useful experience for the Sri Lankan Institute.

2. Study on products and materials

2.1 Investigation of current status of coir composite research

This activity was carried out by searching all available literature resources. Following literature related to coir plastics composite were found :

2.1.1 Fibre cleaning procedures

Ultimate objective of this work is to remove outer most wax layer of the coir fibre, to ensure the proper interaction between fibre and matrix material. Most mentioned method to clean fibres found in literature is distilled water cleaning. A.K. Mohanty (ref. 5) soaked coir with hot water and found an increase of the flexural strength. The so called 'soxhelt extraction' in acetone, followed by distilled water cleaning, and ethanol benzene extraction are also a series of fibre dewaxing procedures that appeared in other research work done by A.K. Mohanty (ref. 4,5). Soaking in acetone and hot detergents are also described as procedures for dewaxing. In some research activities, dewaxing had done after the alkali treatment.

2.1.2 Fibre chemical treatments

Removal of lignin, hemicellulose, silica and pith from the fibre to have better impregnation between fibre and matrix and improving fibre surface roughness to have a better interaction are the main objectives of fibre chemical treatment (ref. 1,2). Also, the ability to rearrange the fibrils is improved by removing lignin and hemicellulose. Such treated fibres are less dense and capable to rearrange inter fibrils regions when subjected to tensile deformation. According to many literature references the NaOH treatment is a simple and effective method to achieve this . The correct balance level of time and concentration of the treatment ensures the optimum mechanical properties. Different concentrations ranging from 0.5 % to 20 % and time of soaking ranging from 15 minutes to 96 hours were observed by many scientists. However, there is no definite research conclusion about concentration and time of treatment with respect to the optimum mechanical properties. Rohatgi (ref. 2) found that 72 hours soaking in 5 % aqueous NaOH gives best UTS and 96 hours soaking in the same concentration give best tensile modules. According to Mohanty's investigation (ref. 3), 2 % NaOH aqueous solution of NaOH for one hour is best treatment for the optimum UTS of the composite while soaking in 5 % aqueous solution of NaOH for 1 hour gives the best flexural properties. Soaking in Na_2SO_3 is another method available for chemical treatment of coir fibre (ref. 6).

2.1.3 Chemical modification

A number of chemical modification methods were found in the research papers. The following methods were described:

1. Impregnation
2. Chemical coupling
3. Acetylation

1. <u>Impregnation of fibre as a chemical treatment:</u>

Impregnation improved the wetability and compatibility between fibre and matrix materials. In this method, fibres are impregnated in a solution of another polymer that is compatible with the matrix polymer, before making the composite. Theory of wetability of natural fibres and simple experimental model to determine the wetability of fibres is explained by Paul (ref. 7). This is to be known as a common method for thermoplastic composites. Xylene-HDPE solution was used by A. Valadex-Gonzaleza (ref. 1) as a treatment for fibre-HDPE composite. A disadvantage is the toxicity of this chemical.
A method for impregnating the natural fibre in a thermosetting composite was also found: impregnating the fibres in styrene before the impregnation of the polyester matrix improves the mechanical properties of the composite. This is an method easy to implement and was also investigated in the vacuum injection trials of this project.

2. <u>Chemical coupling methods:</u>

In this method, the fibre surface is treated with a chemical compound that form a bridge of chemical bonds between fibre and matrix. Several methods have been investigated by the scientists. Some of them are listed below:

1. Graft polymerisation with methyl metha acrylate (MMA)
2. Graft polymerisation with acrylonitrile
3. Esterification with malic anhydride
4. Treatment with iso-cyanates
5. Treatment with triazine coupling agent
6. Treatment with silane coupling agents

Detailed information was found only for first three. Other three methods were just mentioned in several papers as possible methods, but no specific reasearch results were found.

Graft polymerisation with MMA:

Graft co-polymerisation is an often applied method for surface modification of natural fibres. Only few investigated the use of this methodology for coir fibre. A.K. Mohanty (ref. 9), Premamoy Ghosh (ref. 10) and R.K. Samal(ref. 11) studied MMA modification procedures for coir/sisal fibres and their properties. The general polymerisation system is as follows. Alkali treated coir fibres were graft co-polymerised with MMA in a standard reactor vessel, $CuSO_4$-KIO_4 as the initiator system. The reaction is carried out under elevated temperature with reduction of atmosphere pressure. The reactivity is proved by analysis of SEM, FT-IR and measuring the fibre tensile properties. However, scientific articles with composite property measurements were not found.

Graft co-polymerisation with Acrylonitrile:

A.K. Mohanty (ref. 12) investigated the graft co-polymerisation of coir fibres with acrylonitrile. Initiator system and procedure is similar to MMA graft copolymerisation. However, research information on composite properties was not found.

Esterification with malic anhydride:
Here, the surface of the natural fibre reacts with the malic anhydride. This provides a good binding with the styrene in the polyesterresin. With the improvement of fibre resin interaction, especially the strength properties are increased. Aranguren (ref. 13) used this technique to treat wood flour and prepared composite with unsaturated polyester resin. In his study, under the mechanical property evaluation, improvements in compression properties are higher. But improvement of flexural properties of composite panels are marginal .

Scientific articles related to coir fibre with other grafting methods were not found.

3. Acetylation:

The procedure described under this topic is less complicated than the above coupling method, and has more tendency to transfer into industry scale with justifiable cost addition (ref. 14, 15). The procedure involves a reaction between the fibre and acetic anhydride, with or without acetic acid (catalyst), at around 100 °C to 120 °C in a chamber. Reaction time is around 3 hours. Ansell (ref. 14) studied the reactivity of acetylation for different types of natural fibres (coir was not included). H.P.S.A Khlil (ref. 15,16) has done trails with acetylated coir fibre with different matrix materials and found improvements in tensile properties, flexural properties and interfacial shear strength properties.

2.1.4 Other findings in literature

Acrylic resins as binder:

B. Reck (ref. 8) studied the use of acrylic resins as a binder for wood and natural fibres. He investigated the effect of binder content and pressing temperature on mechanical properties for sisal-jute fibres with acrylic binder.

Maleated Polypropylene (MAPP) as a coupling agent in PP-Coir composite:

MAPP treatment is known as the standard coupling method for all the natural fibre composites with PP. However research articles were not found for coir-PP composite in relation with malic anhydride coupling.
As mentioned under the grafting methods, the malic anhydride reacts with the cellulosic. The other side of the MAPP molecule, the PP-chain binds with the PP matrix of the composite. An addition of 2 to 5 % MAPP to the PP is usually applied and gives an improvement of strength properties.
Many articles are available that describe the positive effect of MAPP in a natural fibre - PP composite. However no articles on coir-PP were found.

Natural fibre composite based on processing technology:

In general most articles deal with research done on material level, i.e. fibre treatments are investigated and mechanical properties are measured. Few research articles were found that specifically dealt with a certain processing technology. In most cases test specimen are made by some kind of manufacturing technique, without looking in detail into the processing technique and its optimal processing parameters. For most test specimen the variable and unreliable hand-lay up technique is used. In some cases compression moulding and vacuum bagging were used.

Natural fibre composite in application:

Natural fibre composites in industry applications related research articles are available. Most of these examinations were done for composites based on flax, hemp and sisal. No research articles were found for coir based industrial applications.

2.1.5 Conclusions of literature research

The conclusions of the research on coir fibres found in literature were:

- The research carried out in the past on coir composites is very limited, much more information is available on composites with the other natural fibres (flax, sisal).
- Natural fibre treatment procedures that could also be applied on coir involve cleaning and de-waxing, chemical(alkali) treatment and chemical modification.
- Cleaning and de-waxing can be done by using distilled water, hot water, acetone etc.
- Most popular alkali treatment is NaOH treatment.
- Several chemical modifications were examined by researchers, but non of them improved the fibre properties significantly.
- Composite with natural fibres can be made by using thermosets (epoxy, unsaturated polyester resin) or thermoplastics (polypropylene, synthetic latices such as acrylics)
- Industrial applications based on coir composites were not found.

2.2 Investigation of material and technological properties of coir for composite manufacturing

In the table below, a comparison is shown of the main fibre characteristics between coir and a number of other natural fibres as well as glass fibres;

	Fibres								
Properties	coir	flax	hemp	jute	ramie	sisal	abaca	cotton	E-glass
density (g/cm^3)	1,25	1,4	1,48	1,46	1,5	1,33	1,5	1,51	2,55
tensile strength * (MPa)	220	800-1500	550-900	400-800	500	600- 700	980	400	2400
E-modulus (GPa) specific (E/density)	6 5	60-80 26 - 46	70 47	10-30 7 -21	44 29	38 29		12 8	73 29
elongation at failure (%)	15 - 25	1,2 - 1,6	1,6	1,8	2	2 - 3		3 - 10	3
Relative price compared to coir	100%	200% - 600%	240% - 700%	140%	600% - 1000%	240% - 280%	600% - 1000%	600% - 900%	520% – 600%

* tensile strength strongly depends on type of fibre, being a bundle or a single filament and its treatment

From the table it can be concluded that the most significant differences between coir and fibres as flax or jute are:

- Coir has a lower stiffness (5 - 10 GPa, whereas jute has 10 - 30 GPa)
- Coir has lower strength
- Coir has a relatively high lignin content
- Coir is much cheaper

These are properties measured on fibres alone and not in a composite. The geometry of the cellulose in a coir fibre (hollow and spiral) can cause a low stiffness of the dry fibre, but surrounded in a polymer matrix the cellulose performs better.

Nevertheless the differences between the properties of coir and other natural fibres have their consequences regarding the objectives one should have with coir composites. When using composites in general, one or more of the following aspects are used to benefit from:

1) composites have high strength and stiffness per unit weight
2) composites have a freedom in design. With a number of particular manufacturing techniques it is possible to make very large and complex 3D shaped components, even provides with inserts or sandwich cores
3) composites are durable, fatigue resistant and corrosion resistant
4) resistance to impact because of the capability to absorb much elastic energy
5) thermal, acoustic or electrical insulation

It is clear that if aspect 1) is the main design criterion, other natural fibres will do a better than coir. But regarding the other four criterions coir performs as good as other natural fibres.

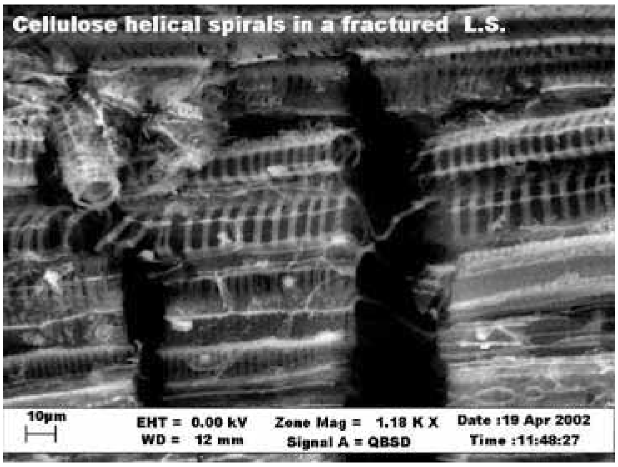
Especially the aspect of freedom in design is interesting. Taken into account the low cost of coir fibres, technologies such as vacuum injection of large complex shapes and the forming out of thermoplastic prepregs are interesting technologies to study with coir.

Research on micro-scale has been carried out at ITI

Purpose was: a) to observe changes in the structure of coir fibre when treated with different treatments and b) to identify suitable fibre treatments method for coir fibres. Fibres and cross-sections of fibres have been observed with scanning electron microscope. It has been carried out for different species of coir. See Appendix A

In this research on micro-scale it was found that the coir fibre has a different geometry and a different chemical composition. Three major differences will effect the ability to be used in composites:

1) The single fibre is thicker and shorter. The aspect ratio (length over thickness) may not be to small in order to have the fibre function well as a reinforcement. This means that short coir fibres are not suitable for using them in composites
2) The fibre has many helical (spiral wise) cellulose components. See Figure below. This phenomena is responsible for a relatively low stiffness of the dry fibre. See picture on the right. The elastic effect of the spiral will be less if the fibre is fully embedded in a polymer matrix. This should be taken into account while processing the fibre into a composite. A proper cleaning and removing of lignin and pectin is therefore essential.



Scanning Electron Microscope picture of the helical shape of some cellulose parts within the coir fibre

3) The fibres have many vascular voids. To obtain an effective composite these voids should be impregnated properly with a polymer matrix. Therefore techniques based on low-viscosity matrix material are beneficial. This makes the thermoplastic prepregging with aqueous emulsions an interesting option.

2.3 Appropriate combinations of products and technologies

Each manufacturing technology has its own possibilities and restrictions.
Given the size of the project, it was impossible to include all existing composite manufacturing processes into the assessment. Therefore a selection was made based on the following criteria:

- **Flexibility** – A coir based composite industry is in the development phase, therefore it is impossible to predict exactly which products will be manufactured eventually. Processes with a high degree of flexibility in product-types have preference.
- **Completeness –** Processes that require a substantial infrastructure, which is presently not available in Sri Lanka and which is expected not to be developed in near future, are not appropriate. Only “stand alone” processes are preferred.
- **Wide scope –** To assess the potential of both thermoplastic and thermoset resin materials, techniques with both types of resin systems were chosen.
- **Availability –** Only technologies and equipment which are readily available at the participating research institutes were taken into account.
- **Input material –** The raw coir material used in the composite should already be manufactured in Sri Lanka. Sri Lankan coir (half-) products, such as non-woven mats should be used as starting point for the manufactory of bio-composites.

Three technologies were selected:

- Vacuum assisted moulding
- LFT Processing
- Compression forming of prepregs (made by monomer or latex impregnation)

A number of possible products have been chosen that could be made with coir composite materials with the mentioned techniques in a cost effective way.

Vacuum injection	Compression forming of prepregs made by latex or monomer impregnation (a GMT-like processing)	LFT compression moulding (based on coir-PP pallets / sticks, or a dry mixture of both)
Large area structural products, such as: - hull of fishing boat - - - -	Structural shell-like products in mid-range series size. such as: - stadium seats - chair back rest -	Structural shell-like products , possibly more detailed and in larger series, such as: - stadium seats - lids for garbage bin Recycled plastic and second hand moulds can be used

2.4 Identifying potential marketability of coir composite products

2.4.1 Raw materials

The two main components are coir fibre and polymers (natural and synthetic). Additional material inputs would be needed to optimise the interaction of these two main raw materials.

coir fibre
Even though there is limited literature on bio-mechanics and the bio-chemical structure of coir fibre, detailed conceptual and experimental work regarding the inter-action of coir fibre and polymers based on bio-chemistry of fibre for the various solutions to maximise fibre/polymer interaction is non-existent. From an industrial perspective this implies that R&D is relatively more "hit and miss" than structured, hence could be time consuming and sub-optimal. It is recognised that this subject was well beyond the scope of the present project, however, suggestions were made by the industry to initiate activities in this area. It is suggested that ITI of Colombo, Sri Lanka explores this issue.

The lack of detail knowledge on how coir fibre (fibre types, bio-chemistry, morphology etc.) behave in polymers and the lack of knowledge of fibre/polymer bonding mechanics also means that predictions as to the outcome of the use of the various types of fibres (green fibres/retted fibres, Mattress/Omat fibre) was a difficult issue. Although some useful research on fibre anatomy and chemistry has been done in this project, described in Appendix A, still much more work on these issues is necessary.
Based on the results described in appendix A, it was decided to carry out the research with retted coir fibres only, in two types namely Mattress and Omat.

polymer
As far as the thermoplastic polymer side is concerned the options are too numerous, even to summarise. However certain polymers such as PP have gained popularity in natural fibre composites.
For the choice of PP big industries such as automotive are responsible and it is mainly based on the low price per kg of PP and its good recyclability.
If in the future the mechanics of fibre-polymer interaction would be better understood, the main approach to the polymer selection should be based on the characteristics needed of the fibre/composite and product characteristics rather than arbitrarily selecting a polymer and then seeking to make a product out of this composite. However, within the limited scope of this project the selection of polymers has been pragmatic.
As far as thermosetting polymers is concerned, the unsaturated polyester was chosen. This choice was based on reasons of availability, low cost and a natural good adhesion with cellulose.

2.4.2 Technology and products

It was essential to recognise the distinction in “technology” related to natural fibre composites. There are certain technologies that are related to the manufacture of “the raw materials” i.e. compounded material and the technology related to the manufacture of products.

Basically, there two different types of result came out of this project.
(1) Semi-finished products i.e. the fibre / polymer compound (e.g. in pellet or impregnated mats etc.) in combination with a suitable manufacturing technology,
(2) Prototypes of products (e.g. end use products or components for assembly or integration into other products)

The R&D done on latex- and MMA-impregnation resulted in both semi-finished products as well as finished products. The vacuum assisted moulding lead to finished products. Unfortunately LFT processing resulted in some first investigations n the technology only. More work has to be done on the development of useful semi-finished material in order to be able to manufacture satisfying prototypes of products.
In chapter 3 details are described on how these products were made.

2.4.3 Market for coir based composites

The main objective of this project was to explore the potential use of coir in composites. The general trend that could be observed is the increase of natural fibre based composites. Until now, coir fibre has not shown the same degree of growth compared to other fibres.

It is often mentioned in literature that coir fibre may not be suitable for composite. This conclusion is mainly based on the assumption that
(a) natural fibre composites must achieve similar mechanical characteristics as carbon fibre or glass fibre composites

(b) In comparison to other natural fibres such as flax and hemp, coir exhibits a much lower stiffness and hence not suitable for composites.

Ad (a) : from other product development activities related to “Green products” industrial companies have noted that “green products” should target their own market segments and not be considered as replacement of existing products e.g. glass fibre. There are several arguments for the use of natural fibre products this should be capitalized.

Ad (b) the biggest flaw in this argument is that most of the results presented are related to R&D studies that have only compared the properties of various composites in semi-finished form. Studies at product level are nearly non-existent. There are no rules saying that natural fibre composites MUST have the same characterises as glass fibre.
From a marketing view point this could be the biggest error in logic when the potential of coir fibre composite is evaluated for its market potential.
There may be several products that could be developed based on the inherent properties of coir fibre. Properties of coir such as fibre morphology, mechanical property (high elongation) and bio-chemistry (high lignin content) need further attention in product development.

Finally it should also be noted that given the nature of coir fibres in relation to other natural fibre combination of fibres (coir/flax) could lead to products that may exhibit superior properties than the use of a single fibre type.

3. Technology development

3.1 Raw materials

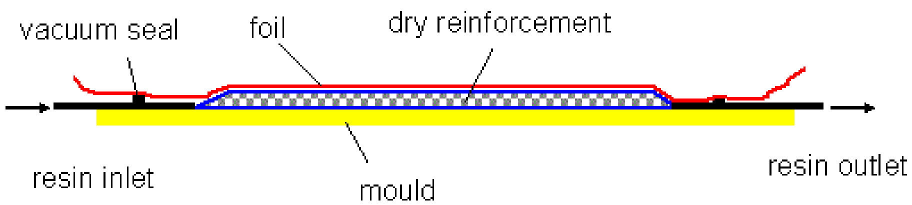
Many types of coir were tested at the ITI. The anatomy of the fibre was studied.
Based on the performed fibre studies, two qualities of coir have been chosen: Mattress and Omat. Both fibres had the best strength properties
A summary of this research is attached in Appendix A.
Coir fibres, both mats and loose short fibres have been provided by Jafferjee's and sent to Delft for further research on fibre treatment and processing technologies.

3.2 Manufacturing of composite specimen

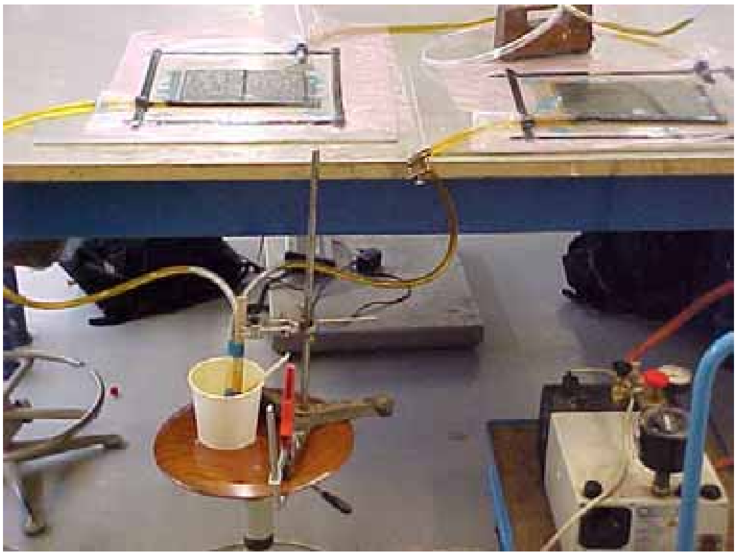
In the original project proposal it was planned to investigate three technologies; a) Vacuum Injection Technology, b) Latex impregnation, and c) LFT processing.
During the project a fourth technology also turned out to be worth investigating, this is the monomer impregnation. This technology was researched with MMA monomer.

3.2.1 Vacuum Injection Technology

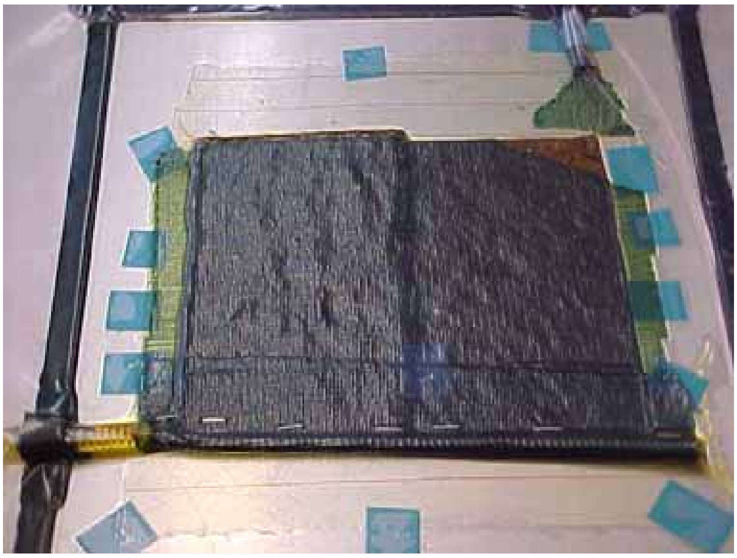
The vacuum injection technology is basically a simple process; First fibres are placed in a mould and they are bagged and sucked vacuum. Then resin is let in, and after complete impregnation and curing of the resin, the product can be taken out of the mould, see below:



Below a picture is shown of the setup of the vacuum injection technology at the laboratory of the TU Delft:



Below an almost complete impregnated coir mat is shown. The resin is injected with polyester resin from the bottom left corner, while vacuum is applied at the top right corner. In that corner a small triangle of the mat is still dry, which can be seen by a lighter brown colour.



Following fibre treatments are observed:

a) cleaning from dirt and waxy substances
b) chemically removing components such as pectin or lignin
c) grafting with a compatibiliser

Many techniques are known from the literature. For the coir used in the vacuum injection process a choice of treatments was made based on simplicity (low cost and low-tech) and based on the typical properties of the coir. Following techniques were used and compared:

1) no cleaning
2) cleaning with hot water

3) treatment in ammonia (NH_4OH) to investigate the effect of a chemically removing the wax layer and the lignin
4) washing in NaOH to investigate the effect of a chemically removing the wax layer and the lignin. Similar to ammonia treatment but it is supposed to be more severe treatment which could have a damaging effect on the cellulose
5) pre-impregnating with pure styrene to investigate the effect of wetting the vascular regions and voids inside the cellulose material

The laminates made with the different techniques were subjected to mechanical tests which are reported in 3.3.

3.2.2 Latex and Monomer Impregnation

The latex impregnation technology, as described in the project plan, has been extended with a similar impregnation techniques: the monomer impregnation.
It also uses the low viscosity of a raw material used to make a thermoplastic.
While a latex is an aqueous solution of a polymer powder,
a monomer solution is a mixture of a monomer and a polymer powder of the same kind.

Both can be obtained as a 'syrup' with a low viscosity allowing a good wetting and impregnation of the porous and hollow coir fibres.
After impregnation and drying a thermoplastic prepreg is obtained. This can be processed in a quick and clean way just as with any other thermoplastic prepreg: heating, shaping and cooling.

For the moment two coir-thermoplastic prepregs were developed:

1) Prepreg made of a 50%-50% blend of Vinamul-3525 (Vinyl Chloride-Vinyl Acetate-Ethylene) and Vinamul-4373 (Acrylic)

2) Prepreg made of a mixture of 90% MMA-monomer and 10% PMMA-polymer powder.

Prepregging with Vinamul Latex

The laminates made with the different techniques were subjected to mechanical tests which are reported in 2.8.

Prepregging with MMA monomer

In the first trials it was found that the polymerisation is disturbed if the monomer solution has contact with oxygen. Therefore it was decided to impregnate the coir mat with the MMA inside a box that is filled with nitrogen.
The steel dish in which the prepreg was prepared was then heated up to 80° C and polymerisation took place quite rapidly. After 15 minutes the MMA was fully polymerised into PMMA and a rigid prepreg could be taken out of the box.
Later, trials were carried out where the impregnation took place in the nitrogen filled box, but then the prepreg was kept outside the box, only between two films that kept out the oxygen. This was also successful, which means that the prepreg manufacture can be easily scaled up towards a line-production, comparable to that of Sheet Moulding Compound (SMC).

The MMA solution


The nitrogen filled box


PMMA-Coir, consolidated sheet (left) and the prepreg (right)

3.2.3 LFT processing

Trials with the LFT piston blender have been carried out.
Materials used:

- Mattress, short (around 25 mm length) coir fibres
- PP beads
- MAPP emulsion.

Procedure of the trials:

The coir fibres were first impregnated with a mixture of MAPP and water. After drying the fibres were mixed with the PP beads. This mixture was inserted in the extruder
Heating time in the extruder: 15 minutes
Heating temperature: 220 - 240 C°
Both temperature and heating time were required in order to get a good molten compound of coir and PP. However, it could be seen that some degradation (browning) of the coir took place.
Below, the manufacture of a cone is shown:

The coir fibre-PP mixture comes out of the extruder

The lump is put in between two moulds and compressed

On the right the LFT-compressed cone

The setup with the extruder and 20 tons press

A major difficulty is obtaining a good mixture of the fibres and the PP beads. Both materials tend to de-mix. The addition of the MAPP emulsion helps. This emulsion makes

the fibres sticky which improves the mixing. However, the combination of loose fibres and PP beads doesn't seem to be the right semi finished material.
A good alternative would probably be the half product supplied by the German company Fakt. This company produces sticks of uni-directional natural fibres coated with a thermoplastic skin. These sticks have a length of 25 to 30 mm and can be made as long as the fibre can be provided as a yarn. Further investigation of this semi-finished product is recommended.

3.3 Effect of treatments on the properties of composite specimen

Working with coir fibres one can easily conclude that there is a big gap between the shape in which the raw material is supplied on the one hand and the quality level required for the use in a composite on the other hand. Contaminations as grease and wax substances should be removed first if a bonding with a polymer matrix material is wanted. So, for a good processing into a composite a fibre treatment is inevitable.
From the literature results as described in chapter 2, a number of treatments were looked at. Costly methods were disregarded as well as methods that were difficult to industrialise or that were heavily polluting. At the end it was decided to test the mechanical properties of specimen based on the treatments with NaOH, NH_4 and hot water.
Below the results are given:

material	fibre vol. content (%)	flex. strength (MPa)	flex. stiffness (GPa)
1 + Vac.Inj.	20	29	2.91
2 + 3 + Vac.Inj.	30	25	1.85
2 + 4 + Vac.Inj.	40	45	2.64
2 + 5 + Vac.Inj.	40	47	2.99
2 + 4+Latex	53	67	3.80
2 + Monomer	-	-	-
2+4+6+ vac. inj.	50	69	3.88

The numbers in the table refer to the following pre-treatments:

1) no cleaning
2) cleaning with hot water
3) washing in ammonia (NH_4)
4) washing in NaOH
5) pre-impregnating with pure styrene
6) hot and wet pressing, 8 bars

4 Prototyping

Two types of appropriate products were chosen:

a) Large shell structures, with possibly complex structures such as sandwiches, high structural quality, small series production, manufactured with the vacuum injection technology

b) Compression formed parts, mass produced and out of thermoplastic prepregs made with the emulsion or the monomer impregnation technique.

This choice is based on the fact that composite products and the typical way of processing these materials is also divided in large complex shell structures on the one hand and more simple, but mass producible parts on the other hand. It is also the major difference between composites with a thermosetting matrix and thermoplastic matrix.

For the first type of products a boat hull is a good example. With glass and polyester the manufacture of hulls of more than 15 meter length has recently been realised, and this seems to be a promising market. In the Dutch R&D project Biolicht a catamaran sailing boat has been built with flax and polyester. The result was rather successful, and after sailing for 5 years in salty and fresh water there are still no problems with respect to durability or damage caused by moisture.

For the thermoplastic composite product, a simple but doubly curved shape was chosen, based on the fact that a this shape resembles the requirements of formability and complexity of this type of products.

Vacuum Injection

Since the vacuum applies 1 bar pressure on the whole surface of the product (no matter how large) this technique allows the manufacture of very large structures, such as boat hulls. For the prototype sample, a model of a water plane floater (with a shape like a boat hull) was chosen. As an example a model (scale 1:3) of that hull was manufactured, see below:


dry coir mats are placed into the mould


material is bagged, package is sucked vacuum and resin is let in



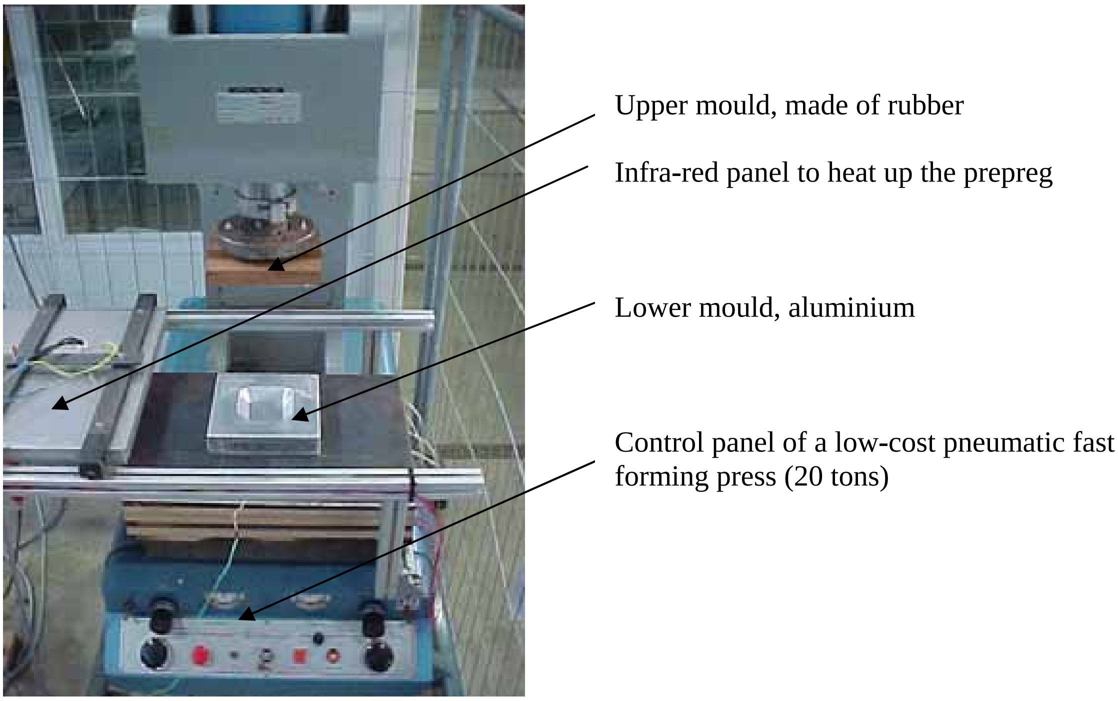
final product in the mould (left) en just released from the mould (right)

The conclusion of the prototyping with vacuum injection technology is that this technology allows the manufacture of large shell type of structures. The coir mat is very suitable, it has a good permeability and it allows an easy placement into the mould. Impregnation with polyester is easy, partially based on a natural good adhesion between cellulose and polyester. This was also observed during the manufacture of small samples.
However, attention should be paid to a proper drying before injection. Moisture disturbs the polyester reaction and at certain spots it will manifests as foaming. At the point of the keel of the hull, there is a resin rich area because the fibres were not positioned very well into the corner. This resin had many bubbles, caused by moisture.

In these type of large surface shell structures, the bending stiffness is often an important property. A higher bending stiffness is quickly obtained by increasing the thickness. This is far more effective than increasing the E-modulus of the material. Often cheap filler materials are used to increase thickness and thus the products stiffness. In this case the coir fibres act as both a cheap filling material as well as a reinforcing material.

Compression Forming with thermoplastic prepregs

The set-up for the compression forming process is shown below:





The manufacture setup consists of

- a low-cost forming press, which is not more than a fast moving, pneumatic cylinder
- an infra-red heating panel, which can be moved horizontally
- a set of moulds, one rigid (aluminium) and one semi-rigid (rubber, 50 to 100 shore)

The steps of manufacture are:

1. The prepreg is placed on top of the aluminium mould, separated by an insulating material,
2. The infra-red panel is transferred to the right and placed over the material and heating takes place (around 1 minute)
3. The infra-red panel is transferred back to its original position
4. The cylinder with the upper mould is moved down and forming and compression of the material in the mould takes place. Pressure on the material is around 10 kg/cm^2.
5. After sufficient cooling (< 1 minute) the press is released and the product can be taken out of the mould.

Both the latex and PMMA prepregs could be formed into shapes easily by this technique. Surface quality has not been optimised yet, this seems not an easy task. The thick fibres and the polymers have a different coefficient of thermal expansion, and a different in shrinkage (which cause a poor surface quality) cannot be prevented. This problem is also not yet solved for glass fibre–PP composites such as GMT.

LFT

With the LFT process no other prototypes were made than the cones as explained in chapter 3.2. A larger and more complicated shape can probably be made with this process, however the required moulds in that case would be extremely expensive and beyond the original budget of this project. Furthermore the results were not satisfying enough (poor mixture and poor impregnation, see paragraph 3.2.3) in order to justify a prototype development.
Pictures of the process and the cone product are given in paragraph 3.2.
Further research and development on an appropriate semi-finished material is recommended, for example the co-extrusion in the shape of a stick as produced by the German company Fakt.

5 The Workshop

In order to create awareness of the potential of coir composites and to obtain industry consensus related to future activities, a workshop was organised in Colombo, Sri Lanka on the 28th and 29th October 2003.

In addition to stakeholders of the coir industry, companies from the plastics and polymer processing industries were also invited to this workshop. This is because these industries are more familiar with the technologies related to natural fibre composites. It is expected that certain synergy's could result from this cross industry cooperation. The Coir Council International (Sri Lankan Coir Industry) and The Industrial Technology Group (ITI) of Sri Lanka contributed towards the organisation of the workshop.

5.1 Objectives of the workshop

1. Share with the participants of the workshop the exploratory R&D results of coir fibre in composites i.e. to demonstrate the potential of coir fibre in composites.

2. To stimulate a discussion regarding industry and the market development activities needed for coir fibre composites and to arrive at an action plan.

In order to facilitate discussions related to objective 1, the results of the exploratory work undertaken at Delft and Colombo was presented. The concept was to exhibit that coir indeed can be used in composites and what type of typical problems one could expect in doing so. Some typical applications will be demonstrated and discussed.
The objective 2 is an industry strategy issue. Given the severe gap of knowledge of coir fibre at present and the limitations related to production infrastructure (material inputs, technical systems etc.) in a typical industrialising country such as Sri Lanka, the challenge is to find practical solutions to industry organisation i.e. how could the opportunities of NFC be exploited and how must the industry be organised to achieve this purpose.
The workshop was held at the ITI institute and took 1½ days.
Selected companies and institutions were invited and it was based on anticipated contribution towards the workshop. The workshop was publicised in the local news papers. FAO Hard Fibre Group Secretariat co-ordinated the International invitations via their mailing list. The program as well as some impressions are shown in appendix C.

5.2 Results of the discussion and plan for the future

The key issues that emerged during the various presentations and discussions are summarised as follows:

Cross Industry co-operation:

- The Sri Lanka Plastics industry has considered Natural Fibre Composites in their strategic industry orientation but decided to deal with this subject some time in

future. The main reason for this is that the industry is operating at full production capacity at present and has priorities related to “normal” production technologies.
- Most the plastics processing technologies are available in Sri Lanka. Mould making is mostly done overseas.
- The plastics industry will show more interest when more tangible R&D results become available. Some participants representing plastics processing companies were keen to contribute towards further development.

Technology issues:
- From the presentations and the exploratory R&D results it is apparent that coir composites could be used in a wide range of existing technologies. However further optimisation of coir fibres, polymers and technology is needed.

Product area:
- Each technology that could use natural fibre / polymer mix as raw materials could lead to different type of products. For example Vacuum Injection would be suitable for small batch production of large 3 dimensional forms; LFT for various large series of 3-D forms etc. Therefore, the choice of how to determine Technology, Product and Market mix remains a complicated and costly issue. This is because NFC could be used in several technologies and result in a wide range of marketable products. There are no known instruments and tools to facilitate the decision process.

R & D capabilities needed for future developments
- It is apparent that the development of Natural Fibre Composites in general and Coir Composites in particular is a complex subject and optimal results (time, finances and capabilities) can be achieved by multi-disciplinary R&D teams and industry.
- The lack of knowledge of coir in general forms a bottleneck. The characteristics of coir must be optimally used for composite applications hence these characteristics and its inter-action with polymers must be well understood. Therefore, the present results are too premature to arrive at definite conclusions. However, the initial results are promising.

Based on the above aspects the workshop discussion focused on two possible options for future action:

(1) Continue future activities at broad level i.e. no choice of product / technology mix. This option would resolve the fundamental issues related coir in composites in relation to certain technologies. Based on these results further activities could be undertaken to converge to product/market mixes.

(2) A choice has to be made as to a technology / product / market mix and focus future activities in this area.

Option 1 : Broad base for future activities	Option 2 : Focused Technology/Product/Market based future activities
Disadvantages: • Perception of no tangible results • Activities remain diffuse • Costly Advantages: • Fundamental issues resolved and opens up route to wide range of applications • Could avoid trial and error of Technology/Product/Market choice • A solid broad foundation for product development	Disadvantages: • The choice of T/P/M would need solid conceptual skills e.g. good understanding of all areas of T/P/M and composites • Sequential i.e. if the wrong choice is made the process must be repeated from start with a new mix • Finding the right persons to facilitate the choice process Advantages: • Perception of tangible activities and results • Could lead to rapid results and hence marketable products

Based on the above considerations the group agreed that the best option would be to make a choice of Technology, Products and Markets and to focus future activities in these areas.

The action plan

The agreed short term actions are:

- With the guidance of the Coir Council International a team of 3 coir companies and 3 plastics companies will be formed. The choice of companies will be based on ability to contribute and the degree of existing technology base within the companies.
- The team will discuss and determine the choice of Technology, Product and Market for Coir composites.
- This team will formulate an action plan within a period of 6 months (i.e. plan should be finalised by May 2004)

6 Conclusions of the Research

The main objective of this fast track project was to determine the potential use of Coir Fibre in Composites. It was exploratory in nature (in the context of Fast Track Project) and intended to demonstrate the potential of coir and guide future detailed R&D and product development activities.

(1) The applicability of coir fibre in combination with polymers
Tests have shown that coir fibre can be used in natural fibre composites. However the tensile strength of coir fibre based composites is lower compared to glass fibre reinforced composites.
The flexural strength varied from 29 MPa – 47 MPa and flexural stiffness of 2,91GPa – 2,99 GPa for coir fibre loading between 20% and 40% and different fibre treatments.
With latex impregnation flexural strength of 67 MPa and stiffness of 3,80 GPa was achieved.
It is reasonable to conclude that these values are comparable to other NF composites.

For methodological reasons (differences in fibre treatment, polymer types, fibre content, structure of fibre, technology used etc.) the above data is not directly compared with other NFC or polymers. However as indicative data the following characteristics are can be used: Hemp-PP flexural strength 50-80 MPa and stiffness 5-7GPa. Flax-resin flexural strength 100 MPa and stiffness 6-8 GPa (RTM-35% w/w fibre). These are data with results on the high side of values.
PP virgin flexural strength is 33 MPa and stiffness 1,82 GPa.

A relative lower strength of coir composites does not have to be a negative aspect because there maybe several non-structural applications where the strength properties of coir composites could meet the technical and product requirements, particularly when the competitive price level of coir is taken into consideration.
The relative position of coir in relation to other natural fibres is still to be investigated in more detail. Initial tests tend to indicate that the performance of coir fibre is lower but may not be that negative in relation other natural fibres as suggested in the literature. Lack of understanding of coir fibre could be a possible explanation for coir not being “seriously” considered in natural fibre composite research to date.

(2) Treatment of coir fibre to enhance fibre-matrix bonding
The lack of understanding of the bio-chemistry of coir fibre remains a stumbling block. Even though anatomical information is available regarding coir fibre structure a clear understanding is needed before definite conclusion could be drawn. In addition the chemical composition of coir fibre particularly in relation to fibre treatment needs future investigation.
Some encouraging results were observed with certain treatment methods but the extend of damage caused by the treatment and the benefits of fibre-matrix bonding needs further study.

(3) Coir Composites – Technology mix
Vacuum injection and latex impregnation technologies show positive results.
The prototypes produced demonstrated the possibility for further development.

At this stage LFT can not be dismissed as unsuitable technology but further investigations are needed to find the optimum way to compound the coir and polymer. When suitable methods are identified for compounding coir and polymers it can be used in existing moulding technologies such as LFT, injection moulding etc.

(4) Future Product Development
In order to accelerate the market penetration of coir composite products cross industry collaboration is needed. Multi-functional teams are an essential part for successful product development in the complicated subject area.
The next stage of development could be the identification of a particular product-technology combination and investigating the viability and feasibility of the combination.

(5) Overall conclusion
This project has shown that coir can be used in composites but certain critical issues must still be addressed and resolved. With the right approach and efforts, within a time horizon of 3 years, coir composite products can be introduced to the markets.

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Appendix A Anatomical study of the Coir Fibre (study undertaken at ITI, Colombo, Sri Lanka)

Introduction

Detailed morphological data of coir fibre was not readily available, until recently.
Hence activities were undertaken at ITI of Colombo, Sri Lanka to get an impression of the coir fibre characteristics.
The following anatomical data is a part of this investigation and contributed towards the initial understanding of the behaviour of coir fibre in composites. However, it must be mentioned that there are several unresolved issues in coir fibre anatomy and biochemistry. With regards to NFC, these issues should be resolved so that optimal fibre treatment methods could be developed.

A1. Surface view of fibres

On the surface fibres display many pin hole like structures, which is known as pits.
The arrangement of these pits are not uniform **(Fig. A01).**

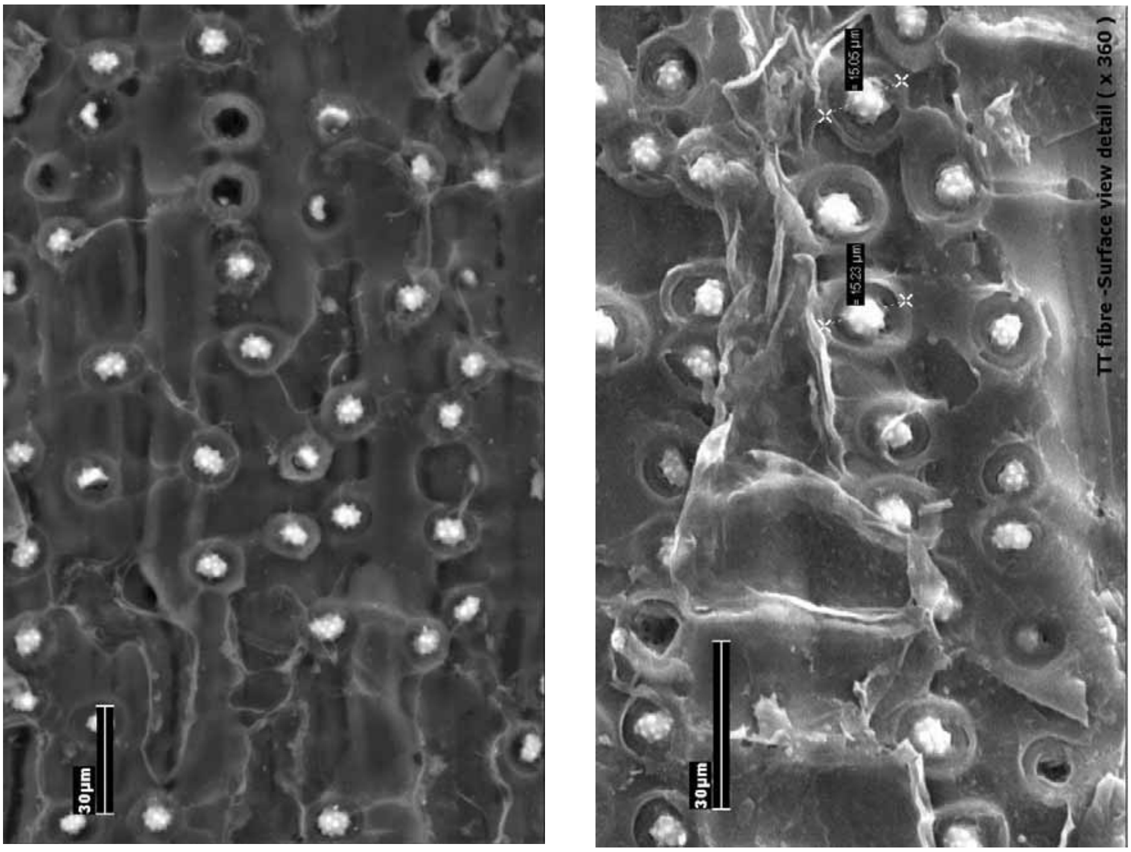

Fig. A01 Scanning Electron Micrographs, magnified surface view of fibres

The pit shape is circular or somewhat irregular. The spaced found inside the pit is called pit cavity.

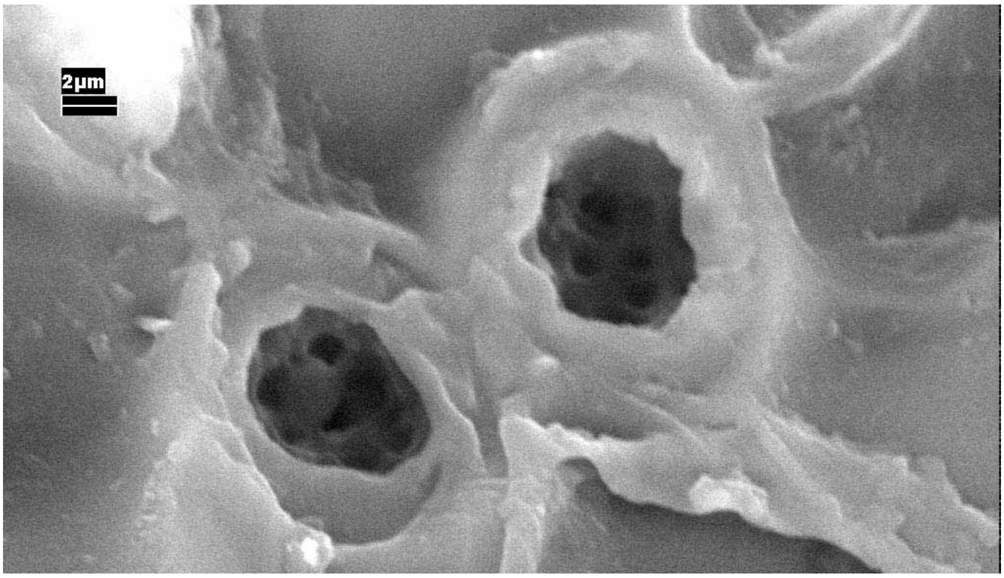

Fig. A02 Scanning Electron Micrograph of a pit

A2. Cross sections

The cross sections of the fibres are rounded to polygonal in shape. The structure is quite simple vascular bundle (blue) surrounded by a sheath of thickened cell layer (red) **see Figure below.**

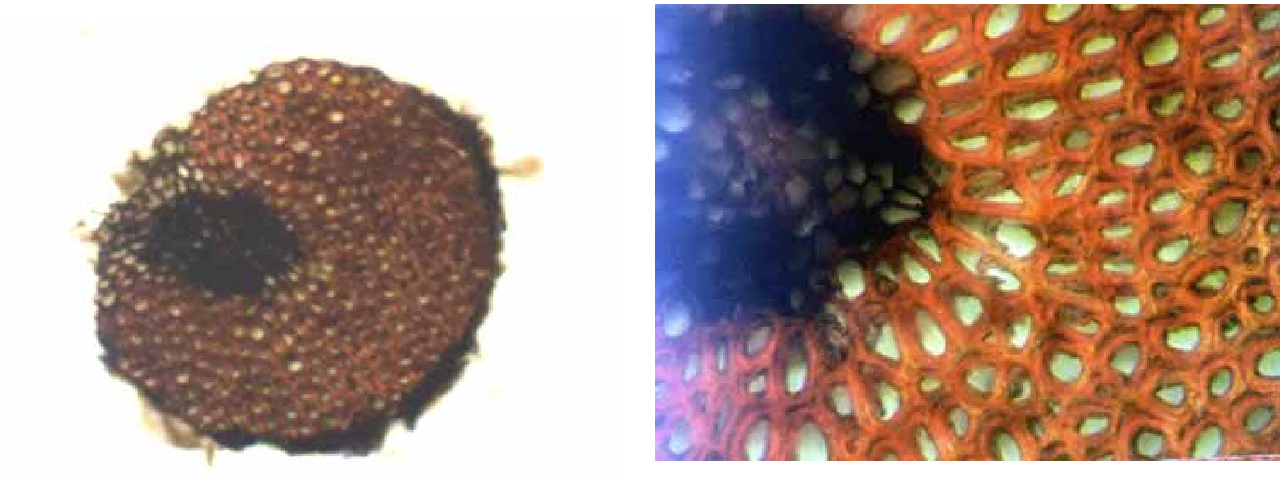

Fig. A03 . T.S. of coconut fibre ; Vascular region (blue) surrounded by thick ***cell layer (red) a – (x10x10x1), b - (x10x40x1)***

In some fibres there is a cavity on the centre **(Fig. A04)**. This may due to the disintegration of the cells in that area. When fibres become mature this will occurs.

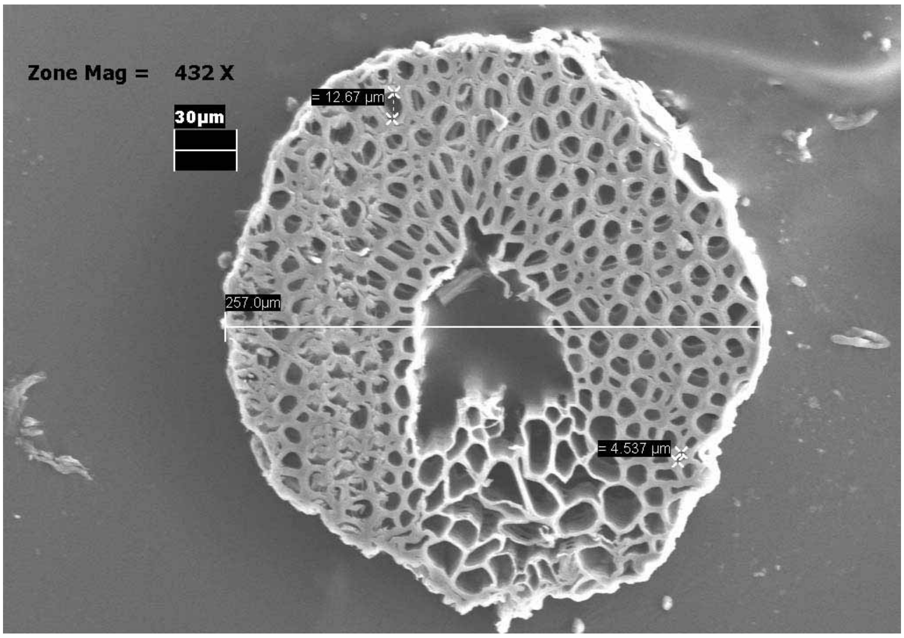

Fig. 04. Scanning Electron Micrographs of cross (Transverse) section of fibre showing central cavity

A3. Longitudinal sections

In longitudinal section it was very clear that fibre consists of several little fibrils (Fig. 05). They are interconnected to each other. Each little fibril has a narrow lumen (in cross section this was appear as pores fig 04) .

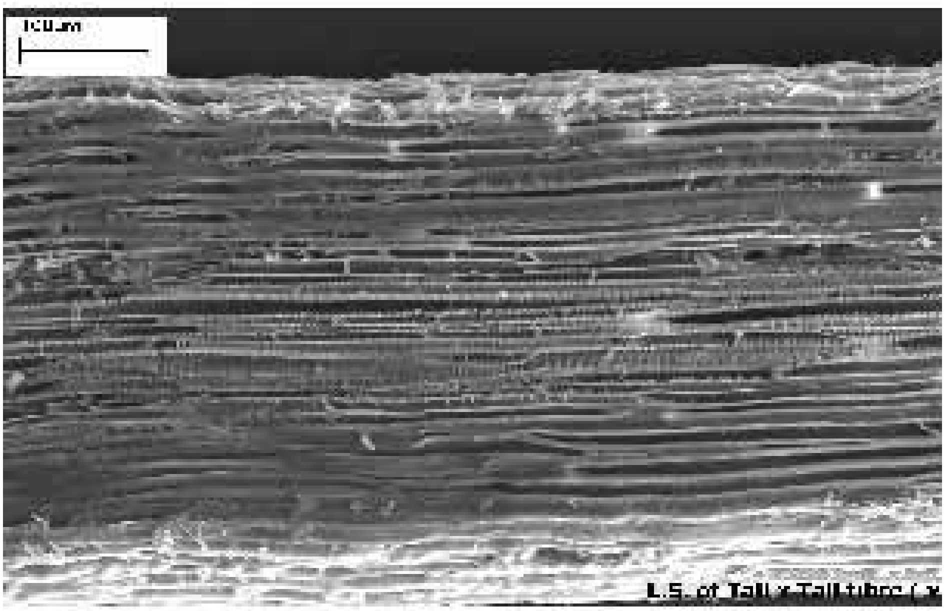

Fig. 05. Scanning Electron Micrographs of longitudinal (transverse) section of a fibre

Appendix B. Participants of the project

The project has been initiated by the following industrial companies and institutions:

JAFFERJEE BROTHERS SRI LANKA

Jafferjee Brothers (JB) based in Colombo, Sri Lanka is a reputed diversified family business. The group has been in manufacturing for more than 50 years and is mainly an export oriented company. The business units within the group are Coir and Coconut products, Rubber products, Tea and Garments. Within the company it provides employment to more than 3000 persons. JB is a major manufacturer and exporter of wide range of coir based products and has been in this market segment for many decades. Some of the coir activities are ISO 9002 certified. Zylyon International BV, The Netherlands is the European office of the JB group responsible for business and product development activities in Europe and Eastern Europe.

Contact: ***Mr. Murtaza Jafferjee – Director - Tel.: +94-11-2432 051***

HAYLEYS GROUP

Hayleys Group, Colombo, Sri Lanka is the largest and most diversified group in Sri Lanka. It is a public company, listed in the Colombo Stock exchange. Hayleys is a major manufacturer and exporter of wide range of coir based products and has been in this market segment for many decades. Some of the coir activities are ISO 9002 certified.

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THE INDUSTRIAL TECHNOLOGY INSTITUTE (ITI)

The Industrial Technology Institute (ITI) is a Statutory Board, which came into existence on 01 April 1998 by virtue of the Science & Technology Development Act No. 11 of 1994. ITI is the successor to the Ceylon Institute of Scientific and Industrial Research (CISIR) which was established as an autonomous corporate institution under a special Parliamentary Act (Act No. 15 of 1955). The Institute functions within the purview of the Ministry of Science & Technology. The ITI is the premier multidisciplinary scientific research and service organisations in the country employing research and technical staff with a wide range of expertise. ITI's wide range of clients and external stakeholders other than the Government, include both the public and private sector in industrial, scientific and commercial sectors, small, medium and large industries, non-governmental organisation and national and international funding agencies.

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UNIVERSITY OF DELFT AND THE CENTRE FOR LIGHTWEIGHT STRUCTURES

The Structures & Materials Laboratory and the Centre of Lightweight Structures TUD-TNO at the Delft University are specialised in the development of advanced materials, structural design and manufacturing techniques for lightweight structures. Their main philosophy is the integration of the design of concepts, materials and fabrication processes into an integrated design procedure. An important pillar of the research form composites, based on both synthetic and natural fibres. Both the Laboratory as well as the Centre of Lightweight Structures have a lot of experience in industrial applications obtained through projects carried out for industries in various branches, such as automotive, aerospace, sports and consumer goods, building and civil applications (bridges). Successful examples are the development of Glare (the high tech material for Airbus' new ultra large aircraft) and the development of the EE10 "Eaglet" airplane in co-operation with ENAER, Chilli. Concerning natural fibre composites, the faculty participated in the "Biolicht" project where applications for trucks, trailers and busses were developed. As a result of that project the Delft University manufactured many prototypes with flax fibre composites, among them a catamaran, an automotive roof panel and sandwich structures. All of them were directly applicable and have proven advantages regarding cost and weight.

For additional information: www.lr.tudelft.nl and www.clc.tno.nl

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