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This report deals with the application of natural fibre composites in the development of rural societies and arose from the overlap of strives of two organisations, which specialise in their own particular area:

1. The Agro-Industries and Post-Harvest Management Service (AGSI) is one of four services of the Agricultural Support Systems Division at the Food and Agricultural Organisation (FAO) of the United Nations. The work of AGSI focuses on postproduction issues, promotes value-added transformation technologies and covers a broad spectrum of activities which include advising governments in order to develop rural societies.
2. The Structures and Materials Laboratory at the Faculty of Aerospace Engineering of Delft University of Technology specialises in the development of lightweight composite structures. Besides applications in the Aerospace industry, the laboratory has co-operated closely with the automotive industry at the application of natural fibre composites and has therefor a substantial amount of knowledge in this field. Concerning composites based on natural fibres; the potential has always been recognised to locally develop natural fibre composites for the local market.

Being an engineer in the field of natural fibre composites with an interest for applications in developing countries I function as the link between the two above-mentioned organisations. During the start-up of a project to transfer composite technology to Vietnam, I noticed that in general people are not aware of the potential of natural fibres in composite applications. When thinking of developing rural societies, the option of natural fibre composites is often overlooked and an opportunity is missed. This report serves the purpose of raising awareness and is specifically aimed at policy makers in the field of development aid. As a consequence, very little technical information is given.

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## Executive summary

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In this report a strategy is introduced to increase the yield of the traditional fibre industry of rural societies. This industry has changed very little throughout ages and still generates money by either (i) exporting raw materials (jute, flax, sisal or coir) or (ii) manufacturing traditional products such as bags, carpet backing, ropes, baskets, brushes and paper. Both have suffered a decrease in revenue in the past years due to stiff competition with synthetic materials and related products.

The strategy discussed in this report aims to add value to the crops by processing the fibres into so called natural fibre composites. Composites are hybrid materials made of a polymer resin reinforced by fibres, combining the high mechanical and physical performance of the fibres and the appearance, bonding and physical properties of polymers. Due to the wide variety of available manufacturing processes, each resulting in their own characteristic products, the design possibilities are numerous. Consequently, a composite product and its manufacturing process can be chosen to best fit the environment in which the products will be made and used. Besides the technical feasibility, manufacturing of composites becomes also financially feasible when using domestically grown natural fibres in combination with simple manufacturing processes. Potential products are roofing panels, fluid containers, bridges and small boats.

Due to the interest of western society in environmental friendly high performance materials, research institutes such as Delft University of Technology already possesses detailed knowledge on natural fibre composites. Using the natural fibre link, which connects the western composite industry to the traditional rural fibre industry, will facilitate the transfer of this knowledge. This link results in four benefits:

- Matching modern and traditional technology
- Compatibility of different cultures
- Increasing use of sustainable, cheap natural resources
- Reduction of investment costs

When starting up a natural fibre composite industry, the benefits can be summarised into Economical, Environmental and Technical, as follows:

- The entire production chain can be developed, maximising the benefits for the targeted country in terms of money and employment.
- Due to the interest on natural fibre composites in western world, targeted countries can participate in co-operative research, participating in globalisation. This is increased when also the export market for natural fibre composites is aimed at.
- Environmental benefits can be found in the sustainable character of the materials used and the fact that NF composites can replace tropical hardwood.
- Working conditions are improved due to the friendly character of the fibres (no skin irritation) and the lightweight property of the products, reducing the physical strain of the work. The latter benefits women largely, since they are well represented in the rural industry.

Projects on the transfer of NF composite technology to various developing countries at different locations of our planet are running and some have already been completed successfully. Everyday more experience is obtained in adapting NF composite for application in developing rural societies.



## Definitions

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Brain-drain:	Loss of knowledge due to emigration of trained personnel.
Composites:	hybrid materials made of a polymer resin reinforced by fibres, combining the high mechanical and physical performance of the fibres and the appearance, bonding and physical properties of polymers.
Consolidation:	Packing and freezing into a solid state of the fibres and matrix by pressing out the remaining air.
Dehusking:	Mechanical removal of the fibre layer from the coconut.
Durability:	The amount of time during which a material or product functions properly.
Filament winding:	Process in which products are made by winding fibres around a rotating mandrel.
Geo-textile:	A fabric, which is draped over the soil to prevent erosion due to wind or water.
Hackling:	Combing of the fibres for removal of the wooden remains and isolation of the clean fibre.
Hot press methods:	Manufacturing technique in which fibres and a matrix are placed in a mould, upon which applied pressure in combination with raised temperature result in the desired product shape.
Impregnating:	Wetting fibres with a polymer matrix.
Laminae:	A composite consisting of a single fibre-layer.
Laminate:	A composite built up out of multiple fibre-layers.
MLSE:	Medium and Large Scale Enterprises (>20 personnel)
Natural fibre composite:	A composite based on natural fibres.
Polymer dispersion (latex)	Mixture of finely divided solid particles in a fluid.
Polymer matrix:	Material consisting of molecules with a long chain-length, supposed to surround fibres in a composite material.
Prepreg:	A composite semi-finished material, which can be shaped and further consolidated upon heating.
Pultrusion:	Continuous production process in which a mixture of fibres and matrix is pulled through a hole with the cross-sectional shape of desired product. Profiles at any length can be manufactured.
Resin Transfer Moulding:	Manufacturing technique in which the matrix is pressed or sucked through the dry fibres to form a composite.
Retting:	The rotting process to remove the fibres from the rest of the plant.



Sandwich structure:	Structure consisting of two stiff skins separated by a core material.
Single step manufacturing:	Manufacturing of a complete construction in one handling. In contrast to manufacturing of multiple parts, which need to be assembled to form the final construction.
Specific Stiffness:	Strength per unit weight.
Specific strength:	Strength per unit weight.
SSCE:	Small Scale and Cottage Enterprises (<20 personnel)
Sustainability:	The amount of “reduced impact” on the environment during the entire lifetime of a product.
Trinity essence:	The integrated design process consisting of concepts, materials and processes. Integration is required to fully use the advantages of composites.
Vacuum forming:	Manufacturing technique in which the atmospheric pressure is used to form a laminate.



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## 1. Introduction

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World-wide various programs run to develop rural societies and to improve living conditions of the poorest social groups on our planet. Keyword in all activities at present is sustainability. After the end of a certain program, the targeted group must be able to continue the introduced activities by itself. An often-used strategy is to improve existing processes rather than implementing new ones. For instance increasing yields of existing crop-fields rather than introducing a total different type of crop. The basic idea is to maximise effect by applying the least possible changes.

In this report a similar strategy is introduced to increase the yield of the traditional fibre industry of rural societies in a sustainable way. Since selling products with added value creates more money than selling raw materials, the strategy aims to increase the value of the harvest by making sophisticated products out of the raw natural fibres, so called natural fibre composites (NF composites). NF composites products are constructions made of “glued-together” natural fibres. Although the involved processes and products are adapted to the rural situation, the technology is directly linked to the state of the art aircraft and space industry. Hence, the involved materials and processes are widely researched upon and are ready to be implemented outside the western world.

In chapter 2 a brief introduction on composites is given including a historical overview and related processes. Chapter 3 describes the most common natural fibres and the importance of the roll the rural society plays on a national scale. NF composites and general applications are discussed in chapter 4 as well as applications specifically developed to be (i) designed, (ii) manufactured and (ii) used in rural societies. In chapter 5 NF composites are regarded from a technology-transfer point of view and benefits are mentioned in chapter 6. Example transfer projects are presented in chapter 7. Conclusions are drawn in chapter 8.



## 2. Composites

In this chapter a technical and historical introduction on composites is presented. An overview of the most common production processes is given. At the end an integrated design process, typical for composites, is discussed. At the end the relevance of composites for industrial and socio-economic development in developing countries is discussed.

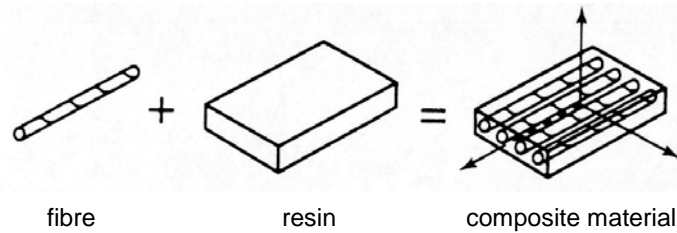


figure 2.1: Composite composition

### 2.1 Composites in general

Composites are hybrid materials made of a polymer resin reinforced by fibres, combining the high mechanical and physical performance of the fibres and the appearance, bonding and physical properties of polymers, see figure 2.1. The short and discontinuous fibre composites are responsible for the biggest share of successful applications, whether measured by number of parts or quantity of material used. Less visible however, but growing enormously since the last decade, are the applications of continuous fibre reinforced polymers. Instead of mass-manufactured polymer-based products, the domain for continuous fibre reinforced composite parts is in general with advanced capital-intensive materials and products. By changing the direction of the fibres in the resin, the material properties can be tailored to the external loads. To optimise the construction multiple adjusted layers (laminae) can be used to form a laminate, see figure 2.2. Typical fibres are glass, carbon, aramid and natural fibres. Epoxy, polyester and polypropylene form common resins.

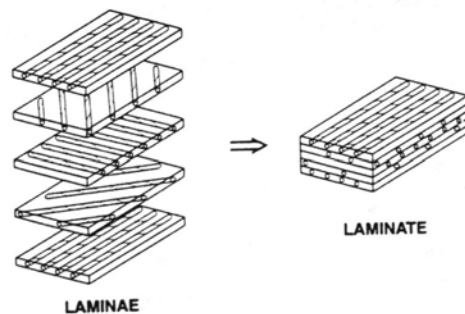


figure 2.2: Tailored composite

By this joining, the poor capabilities and drawbacks of the individual components disappear. For instance, composites combine a high stiffness and strength with a low weight and their corrosion resistance is often excellent. Composites have worked their way up amongst wood and metal due to their outstanding price performance ratio during a lifetime. A powerful approach in improving this ratio is to minimise the steps required from raw material to end product. Composites have the capability of materialising into a structure in a single step, see figure 2.3. Additional economic benefits are the inexpensive raw materials (e.g. when using reinforcements as glass fibre or natural fibre) and the little to none required maintenance during service. Composites are now a part of everyday life, and have entered nearly all major industrial sectors, including aerospace, ground transport, packaging, sports industry and civil engineering. Most current applications are modern; however, some are in fact quite ancient.



figure 2.3: Single step manufacturing. Left: “old” multiple parts car dashboard. Right: Integrated “new” composite design of the same dashboard

## 2.2 Historical overview

### Past

After making and controlling fire and inventing the wheel, spinning of continuous yarns is probably the most important development of mankind, enabling him to survive outside the tropical climate zones and spread across the surface of the Earth. Flexible fabrics made of locally grown and spun fibres as cotton, flax and jute were a big step forward compared to animal skins. More and more natural resources were used, soon resulting in the first composites; straw reinforced walls, and bows (figure 2.4) and chariots made of glued layers of wood, bone and horn. More durable materials as wood and metal soon replaced these antique composites.

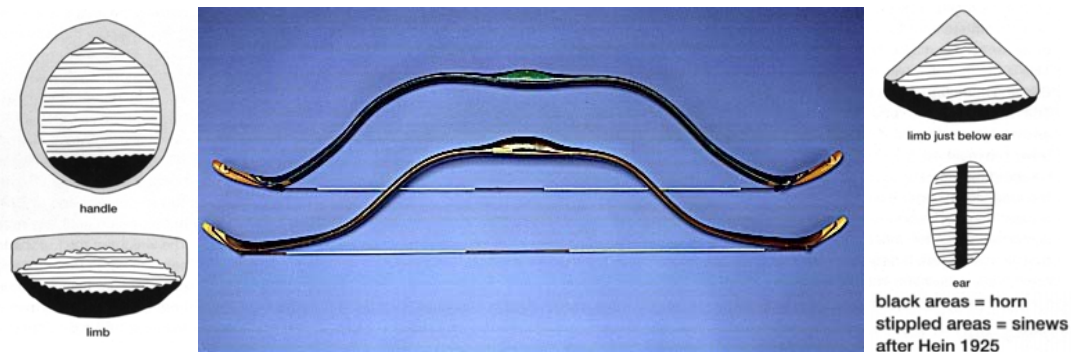


figure 2.4: Composite Korean bow

### Present

Originating from early agricultural societies and being almost forgotten after centuries, a true revival started of using lightweight composite structures for many technical solutions during the second half of the 20<sup>th</sup> century. After being solely used for their electromagnetic properties (insulators and radar-domes), using composites to improve the structural performance of spacecraft and military aircraft became popular in the last two decades of the previous century. First at any costs, with development of improved materials with increasing costs, nowadays cost reduction during manufacturing and operation are the main technology drivers. Latest development is the use of composites to protect man against fire and impact (figure 2.5) and a tendency to a more environmental friendly design, leading to the reintroduction of natural fibres in the composite technology, see figure 2.6. Increasingly nowadays, the success of composites in applications, by volume and by numbers, can be ranked by accessibility and reproducibility of the applied manufacturing techniques, see section 2.3.



figure 2.5: Lightweight composite military helmet



figure 2.6: Interior parts of the Mercedes A-200 reinforced by natural fibers

### *Future*

In future, composites will be manufactured even more according to an integrated design process resulting in the optimum construction according to parameters such as shape, mass, strength, stiffness, durability, costs, etc. Newly developed design tools must be able to instantaneously show customers the influence of a design change on each one of these parameters.

### **2.3 Manufacturing processes**

In this paragraph the most commonly used manufacturing processes are introduced. Although many variants on these techniques exist, this overview gives a good indication of production possibilities.

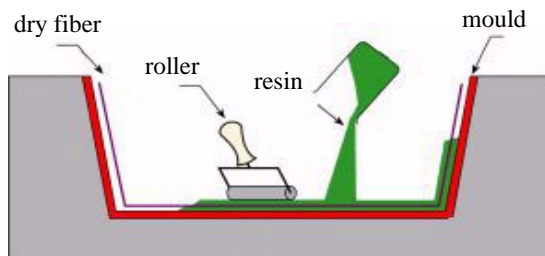


figure 2.7: Hand laminating



figure 2.8: Boat hull

### *Hand laminating*

The fibres, usually mats, are cut and placed in a mould, see figure 2.7. The resin is applied by rollers. One option is to cure while using a vacuum bag, then it's called vacuum bagging. By applying vacuum, excess air is removed and the atmospheric pressure exerts pressure to compact the composite. A possible product is the boat hull shown in figure 2.8. The advantages are the high flexibility and the simplicity of the process and the cheap tooling. The long production time, the labour intensive character and poor possibilities for automation are considered to be disadvantages.

*Resin injection techniques*

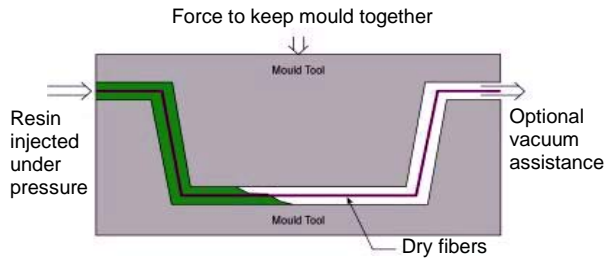


figure 2.9: RTM principle



figure 2.10: Vacuum injection of a boat hull

The fibre mats are placed inside a mould. In case of Resin Transfer Moulding (RTM), this mould consists of two solid parts, see figure 2.9, whereas with vacuum injection a single solid mould and a foil are used, see figure 2.10. A tube connects the mould with a supply of liquid resin, which is pumped or transferred through the mould, impregnating the fibres. After curing the mould is opened and the product is removed. The big advantage is the capability of rapid manufacture of large, complex, high-performance structures, such as the F22 frames presented in figure 2.11.



Figure 2.11: Composite structural parts of F-22 Raptor

*Hot press methods*

Composite pre-forms (already mixed resin and fibres) are inserted in a mould and are cured using pressure and heat. Various methods exist. With injection moulding, resin granules and short fibres are mixed and transported to the mould by a spindle, see figure 2.12. In this way very complex products, like housings of telephones, TV's, cameras and keyboard parts can be made. With sheet moulding reinforced mats are placed in a press, see figure 2.13. Various other hot press methods exist.

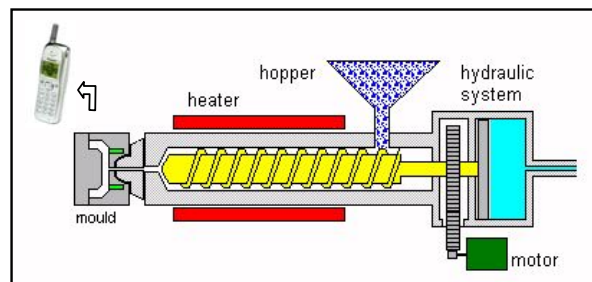


figure 2.12: Injection moulding of a telephone cover

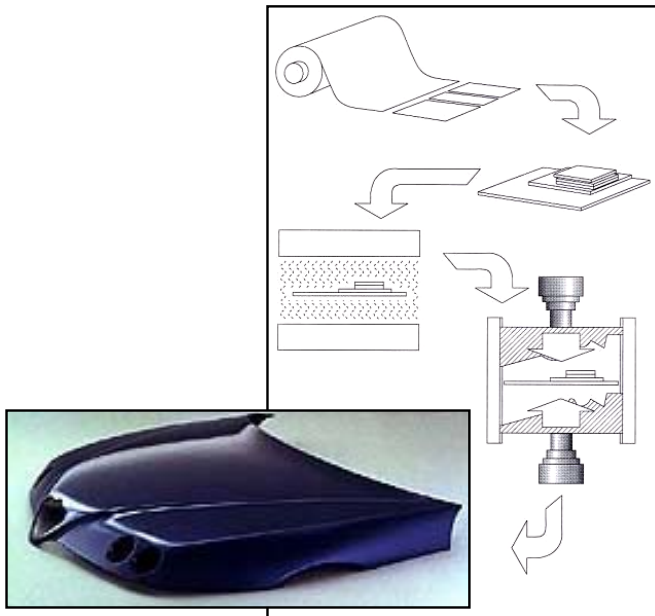


figure 2.13: Sheet moulding of a Alfa Romeo car hood

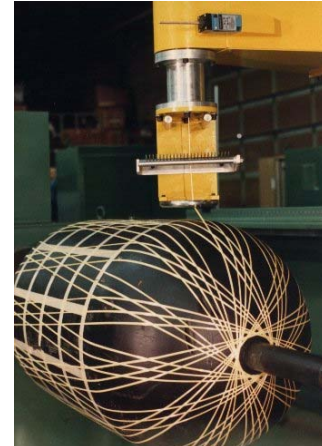


figure 2.14: Filament winding



figure 2.15: Composite LPG container vessel

### Filament winding

Filament winding is a process in which continuous fibres or tows are wound over a rotating mandrel, see figure 2.14. They can be resin-impregnated before, during or after placement. The advantages of filament winding are the repetitiveness of an accurate fibre placement, the use of continuous fibres resulting in high strength and the possibility to construct rather large structures. The disadvantages are the requirement of a removable mandrel (not with all applications) and the hard to define outer surface. A typical product is a LPG container, see figure 2.15.

### Pultrusion

Pultrusion is a continuous process to manufacture composite profiles at any length. The impregnated fibres are pulled through a hole (the heated mandrel), which is shaped according to the desired cross-section of the product, see figure 2.16. The resulting profile is shaped until the resin is dry. The advantages are the manufacturing of thin-wall shapes of "endless" length (figure 2.17), large variety in cross-sectional shape and the possibility for a high degree of automation. Disadvantage is the restriction to one cross-section, shape variation in transverse direction is not possible.

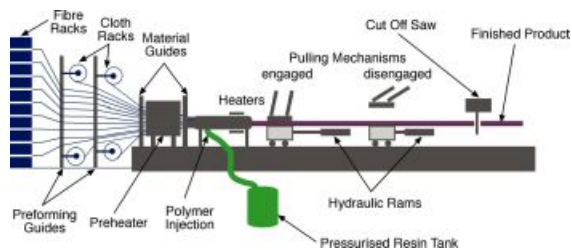


figure 2.16: Pultrusion principle

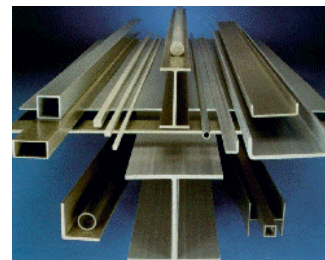


figure 2.17: Pultruded profiles

## 2.4 Design philosophy

As mentioned, the big advantages of composite products are that they can be tailored according to the external loads and that single step manufacturing is possible. To fully utilise these two properties, product design is an integrated process involving concepts, materials and manufacturing processes; the trinity essence, see figure 2.18. Due to integrated design, the product can be optimised in terms of costs, manufacturing time, weight, etc. according to market demand.

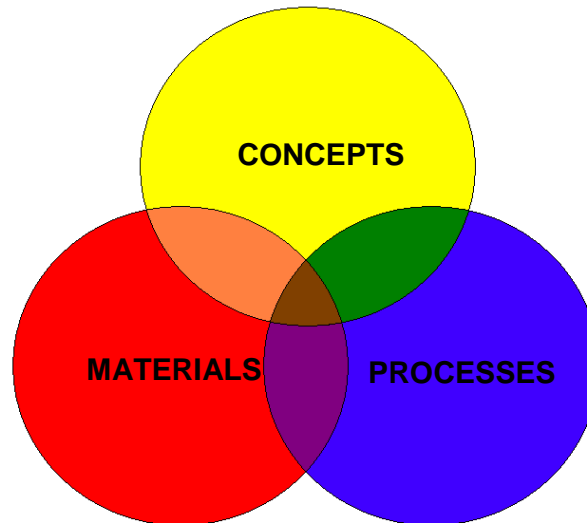


figure 2.18: Trinity Essence

For instance, using this integrated design philosophy, a composite chassis-less trailer (figure 2.19) is manufactured with a 30 % weight reduction compared to a conventional trailer provided with a steel chassis. Due to the lower weight and an aerodynamic shape, fuel consumption is significantly reduced, has a positive effect on costs and the environment.

An example of cost-reduction can be found in composite bridges. Although manufacturing of such a bridge is more expensive than of a traditional bridge out of steel and concrete, the lower weight saves a lot of money on the costs of the foundation and on transport costs. In addition, the higher resistance against corrosion requires less maintenance whereas in general the lifetime is much longer. All benefits mentioned lead to a significant long term cost reduction.

Manufacturing of pressure vessels with filament winding, see figure 2.15, is a very rapid process. Significant reduction in production time is achieved compared to the welding of a similar metal pressure vessel. Secondly, the weight of the wound vessel is significantly reduced compared to a steel one.



figure 2.19: Composite trailer

## 2.5 Relevance for developing countries

In this chapter an introduction was given on composites and various products were mentioned. Highly advanced products in the military and transport areas were discussed. The question rises, what aircraft parts and lightweight trailers can contribute in developing a country? The purpose of this chapter is not in the first place to show how advanced the products and manufacturing processes are at present, but more to show the capabilities of the material and the wide variety of production processes resulting in a large range of applications. By choosing from the wide range of available resins, fibres, fibre placement and production processes a very specified product can be manufactured. All applications shown in this chapter fulfil a need, a need existing in the modern western society. By designing according to the “trinity essence”, composite products can be tailor made to fulfil a specific need.

In developing countries, different needs exist, often of a more basic character. Applications that come to mind are bridges, construction materials for the building industry and water tanks. For these products less sophisticated resins and fibres are required than for aeroplanes and spaceships and domestically grown natural fibres (see chapter 3) can be applied, significantly reducing cost. In addition, the accuracy of the manufacturing processes can be lower as well, allowing a simplification in machine lay-out and operation. So, by designing according to the “trinity essence”, products can be manufactured (using less sophisticated and cheaper materials and processes) that fulfil a specific need, hence contributing to the development of a country.



### 3. Natural fibres

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First the fibre classification and some general aspects are presented followed by a summary of the most widely applied natural fibres, involving quantities, harvesting methods and properties. A closer look will be given at the manufacturing of traditional natural fibre products as part of the rural industry.

#### 3.1 Fibre classification

Natural fibres, often referred to as vegetable fibres, are extracted from plants and are classified into three categories, depending on the part of the plant they are extracted from.

1. *Fruit fibres* are extracted from the fruits of the plant, they are light and hairy, and allow the wind to carry the seeds.
2. *Bast fibres* are found in the stems of the plant providing the plant its strength. Usually they run across the entire length of the stem and are therefore very long.
3. Fibres extracted from the leaves are rough and sturdy and form part of the plant's transportation system, they are called *leaf fibres*.

When determining the properties of natural fibres, one has to keep in mind that one is dealing with natural products with properties that are strongly influenced by their growing environment. Temperature, humidity, the composition of the soil and the air all effect the height of the plant, strength of its fibres, density, etc. Also the way the plants are harvested and processed results in a variation of properties.



figure 3.1: Cotton. Left: processing. Right: Field Cotton

#### 3.2 Common natural fibres

After introducing some fibres a property table is given in table 3.1

##### Fruit fibres

###### *Cotton*

Cotton, see figure 3.1, is world-wide one of the most important fibres used in the textile industry. Picking is highly labour-intensive, and on large scale is often carried out by machine. In many parts of the world, however, picking is carried out by hand. The picked cotton, so called 'cotton wool' is baled. The seeds, dead leaves and other debris are removed by ginning. The clean cotton is baled again and is ready to be spun.

In comparison with other natural fibres, Cotton is rather weak. It can absorb moist up to 20% of its dry weight, without feeling wet and is also a good heat conductor. Cotton is applied for the manufacturing of clothes, carpets, blankets, mobs and medical cotton wool.

### *Coir (Coconut fibre)*

Coconut fibre is obtained from the husk of the fruit of the coconut palm, see figure 3.2. The trees can grow up to 20 m, making harvesting a difficult job. People or trained monkeys climb the tree to pick the nuts, or a pole with an attached knife is used. The fruits are dehusked with on a spike and after retting, the fibres are subtracted from the husk with beating and washing.

The fibres are strong, light and easily withstand heat and salt water. After nine months of growth, the nuts are still green and contain white fibre, which can be used for the production of yarn, rope and fishing nets. After twelve months of growth, the fibres are brown and can be used for brushes and mattresses.



figure 3.2: Coconut palm



figure 3.3: Raw jute in a retting tank

### **Stem fibres**

#### *Jute*

The fibres are extracted from the ribbon of the stem. When harvested the plants are cut near the ground with a sickle shaped knife. The small fibres, 5 mm, are obtained by successively retting in water, see figure 3.3, beating, stripping the fibre from the core and drying.

Due to its short fibre length, jute is the weakest stem fibre, although it withstands rotting very easily. It is used as packaging material (bags), carpet backing, ropes, yarns and wall decoration.

#### *Flax*

When ripe, the plants are pulled from the ground rather than cut, to avoid loss of fibre length from the stubble left in the field. Pulling flax by hand is very laborious work. The flax is dew- or cold/warm water retted before being rinsed and dried in the fields, see figure 3.4. Flax dressing (a process consisting of beating, shaking and hackling) is used to extract the fibres from the stem, see figure 3.5. The fibres are baled and ready to be spun.

Flax is a strong fibre with an increase of strength of 20% in wet conditions [Van Oss, 1973] and it can absorb 20% moist without feeling wet. The elastic fibre degrades due to sunlight and burns when ignited. Flax has good heat conducting properties, is hard wearing and durable. However, constant creasing in the same place in sharp folds tends to break the fibres. Flax is used for the production of linen and canvas, ropes and sacks.



figure 3.4: Fiber stems drying on the field



figure 3.5: Separating the fibers from the stem

### *Ramie*

The Ramie plant (2 m high) can easily grow in tropical regions. Ramie is usually harvested by hand. Retting is a more complex process due to a gummy substance surrounding the fibres, which has to be removed with chemicals. This process is expensive and difficult to control, often resulting in a damaged fibre.

Ramie is an expensive and durable fibre and can be dyed very easily, and is therefore more often used in decorative fabrics than as construction material. Applications are curtains, wallpaper, sewing thread and furniture covers.

### *Hemp*

The plant itself, see figure 3.6 can be grown without artificial fertilisers and weeds don't stand a chance because hemp covers the entire ground within 4 weeks. The production is very labour intensive, especially the separation of the fibres from the bast. After mowing, the stems are dew or water retted, dried and hackled to remove the fibres. Breaking softens the fibres and the top and bottom (bad) parts are removed.

A Hemp yarn is strong and has of all natural fibres the highest resistance against water, but it shouldn't be creased excessively to avoid breakage. The fibre is used for the production of rope, fishing nets, paper, sacks, fire hoses and textile.



figure 3.6: Hemp



figure 3.7: Sisal

## Leaf fibres

### Sisal

The plants look like giant pineapples, see figure 3.7 and during harvest the leaves are cut as close to the ground as possible. The soft tissue is scraped from the fibres by hand or machine. The fibres are dried and brushes remove the remaining dirt, resulting in a clean fibre.

Sisal produces sturdy and strong fibres that are very well resistant against moist and heat. It is mainly used for ropes, mats, carpets and cement reinforcement.

In table 3.1 properties of the natural fibres are presented and compared to the properties of glass fibre. With respect to the natural fibres one has to keep in mind that large variation in properties exist due to natural circumstances.

Property	Glass	Flax	Hemp	Jute	Ramie	Coir	Sisal	Cotton
Density [g/cm <sup>3</sup> ]	2.55	1.4	1.48	1.46	1.5	1.25	1.33	1.51
Tensile strength [N/mm <sup>2</sup> ]	2400	800-1500	550-900	400-800	500	220	600-700	400
Stiffness [kN/mm <sup>2</sup> ]	73	60-80	70	10-30	44	6	38	12
Elongation at break [%]	3	1.2-1.6	1.6	1.8	2	15-25	2-3	3-10
Moist absorption [%]	-	7	8	12	12-17	10	11	8-25
Price of raw fibre [\$ /kg]	1.3	0.5-1.5	0.6-1.8	0.35	1.5-2.5	0.25-0.5	0.6-0.7	1.5-2.2

table 3.1: Natural fibre properties compared to glass

### 3.3 The rural industry

In most developing countries in Africa, Asia and Latin America, agriculture fulfils a major economical role which is confirmed by its large contribution to the Gross Domestic Product (G.D.P.) and its high employment rate. In the early days of development aid, this sector was particularly targeted. Sustainable agricultural improvements were made in the field of erosion prevention, crop spraying, soil fertilisation, irrigation techniques and crop quality. With the aid received from western countries, agricultural societies were slowly turned into massive plantations providing not only themselves, but also western enterprises their required cheap natural resources or to produce mass export products. During this transformation, a lot of labour was required to conduct all necessary agricultural changes.

In the 80's, this transformation was completed, resulting in a large number of agricultural-“educated” unemployed, unqualified to work in modern urban industries. At this point the rural industry gained importance, providing work for those, who could work with indigenous agricultural based technology instead of with modern western technology. Besides compensating for the general loss of jobs in agriculture, it also provides employment for “superfluous” farmers during the off-crop season. Since primitive technology is used, this sector is easy accessible. Manufacturing is concentrated in the food processing, textiles and garments, wood products (figure 3.8), and clay product (figure 3.9) categories. Besides its direct employment, rural industry also generates agricultural employment in rural trade, transport and services.



figure 3.8: Manufacturing of a basket using indigenous knowledge (Bangladesh)



figure 3.9: Traditional pottery in Zimbabwe

Another necessity of developing the rural industry becomes clear from a look into the future. It is predicted that, even with a rapid growth of the urban industry, the rural society of many developing countries will still increase in the next 30 to 40 years. By the time this society ceases to grow in absolute terms, it is already a multiple of its present size. This forecast is alarming considering the fact that it suggests that a large number of people will become reliant upon traditional rural technologies, which is presently very unproductive.

Within the rural industry, the following general distinction can be made:

1. *Medium and Large Scale Enterprises (MLSE)*

These enterprises employ over 20 personnel and manufacture mass products from natural resources for the export market. Since the main reason for export is profit maximisation, output and quality are consequently high and the work is done year-round. Modern technology, often transferred from the west is used. The high level of economic-decision-making involved, traditionally makes it a sector dominated by men. Within the rural industry MLSE provide the least employment, but is the most continue.

2. *Small Scale and Cottage Enterprises (SSCE)*

Employing less than 20 personnel, the workforce is limited to family labour. SSCE manufacture cheap, low-quality products from local natural resources, providing the local market, which consists of poor customers. Applied technology is mainly traditional and indigenous. SSCE originates from household industry to provide the own family with food and articles of use, traditionally the task of women. For this reason SSCE are an important source for employment of women. Total number of employment fluctuates, but peaks in the off-crop season. In general this sector is larger regarding employment than MLSE. An interesting aspect is the development of so-called clusters, consisting of various SSCE. Although within these clusters competition exists between the various SSCE, some form of co-operation is present as well. One can think of collective growing and harvesting of the fields or the shared ownership of equipment. Often management rules are developed, group size is known and enforced and sanctions work to insure compliance. Another form of co-operation within a cluster is the joint transport of products to the market. Due to the advantages of clustering, villages or whole regions tend to specialise in the manufacturing of a single product.

The rapid development of MLSE is directed at the export market and since SSCE aim at a totally different market, their coexistence is explained. In addition, the cheap labour involved in SSCE and the fact that due to improved infrastructure the market for SSCE has expanded towards urban areas, combined with the advantages of clustering, clarify their still thriving existence. There are examples of SSCE supplying the export market by means of subcontract relations. Large disadvantage for SSCE is the fact that due to their small scale and non-continuous character they often don't qualify for government support. In figure 3.10, the rural (fibre) industry is schematically shown.

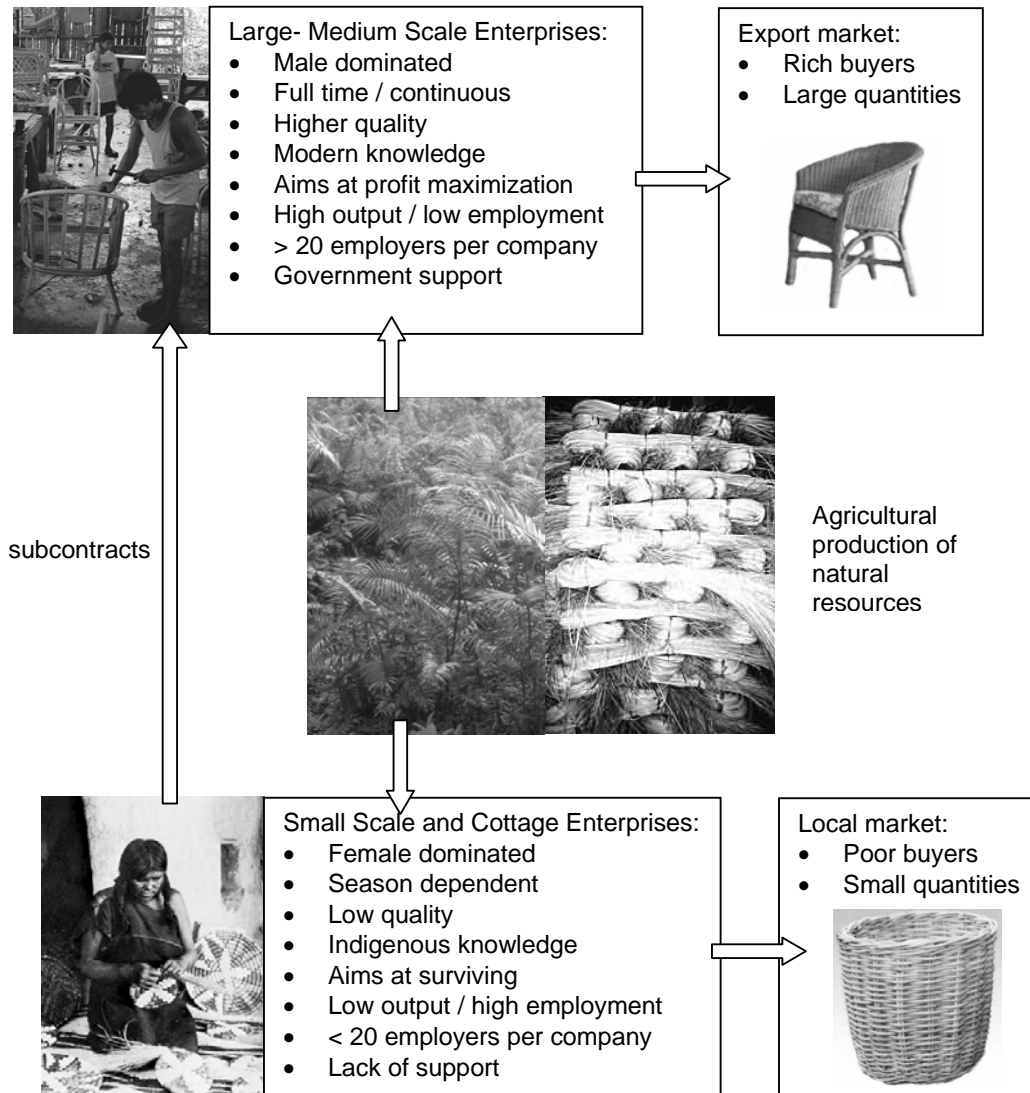


figure 3.10: Schematic representation of rural (fibre) industry

### 3.4 Traditional rural fibre industry

After the production of the raw fibres, consisting of sowing, growing, harvesting and fibre extracting, they are further processed by the rural fibre industry. Being part of the rural industry, the same distinction into MLSE and SSCE can be made. The first step often carried out by these enterprises is selecting the fibres. Often the application of the fibre depends on its length. For example, if a fibre is too short it can't be spun into a yarn and application is limited to filling material. After selection, the long fibres are spun into yarns or ropes, which can be further processed into fabrics by weaving. The fibres (loose filling fibre, yarns or fabrics) are now ready to make products from. The output can be divided into 5 groups, presented in table 3.2. Various examples are given in figures 3.11 to 3.13. In the next chapter, application of natural fibres as filling or reinforcing material in NF composites is discussed.

Group	Uses	Fibres
Fibres used for the manufacturing of fibres	Fibres of sufficient fineness to be manufactured into higher quality fabrics: luxury clothing, laces, domestic and commercial fabrics, decorations, tents, sails, etc.	Principally cotton; also flax, hemp and ramie
	Fibres for coarser fabrics: sacks, bagging, floor covering, carpet backs, etc.	Principally jute; also flax, hemp, cotton and sisal
Cordage fibres	Tying twines	Jute, cotton and hemp
	Rope and binder twine	Sisal, coir and jute
Brush and plaiting fibres	Soft and hard brushes	Sisal and coir
	Braided articles: hats, mats, baskets, rugs, etc.	Sisal
Filling fibres	Stuffing material: upholstery, mattresses, etc.	Cotton, sisal and jute
	Packing material: seams in vessels, barrels, piping, etc.	Hemp and jute
	Reinforcing materials: plastics, wallboards, etc.	Sisal, hemp and jute
Fibres for papermaking	All kinds of paper	All natural fibres, often combined with wood pulp

table 3.2: Output of the rural fibre industry



figure 3.11: Sails made of a natural fibre fabric



figure 3.12: Sisal bags



figure 3.13: Jute yarns



## 4. Natural fibre composites

The natural fibres presented in the previous chapter combined with a resin result in natural fibre composites (NF composites). In this section suitable resin materials are introduced and NF composites in general are discussed, followed by an overview of new product developments for rural societies.

### 4.1 Resin materials

In combination with a suitable resin, the aforementioned natural fibres can be turned in to NF composites. The resin is applied as a liquid and turns solid upon drying. Whereas the fibres add strength to the composite, the resin must at least have the following characteristics:

- **Good impregnation**  
To allow all the different fibres to act as a single material, even the smallest fibres have to be 'glued' together by the resin. The better the impregnation the higher the load a composite can carry.
- **Control moisture content of the natural fibres**  
After processing, the natural fibres still contain a significant amount of water. The strength of the fibre is highest at a certain percentage of moist. Therefore the fibre must neither be too dry or too moist. The resin must allow evaporation of superfluous moist before it forms an impermeable solid film.
- **Non-toxic**  
Since in most of the rural societies health regulations at the work-floor are absent, application of toxic materials will be an act of violence.
- **High availability**  
Usually a higher availability results in a reduction of material costs.

Possible interesting resin materials for the manufacturing of NF composites in developing countries are presented at the next page:



figure 4.1: Tapping of natural rubber latex at the rubber plantations

### *Polymer dispersions (latices)*

Polymer dispersions are a mixture of finely divided solid particles in a fluid, usually water. The use of water instead of a chemical solvent results in a non-toxic character. The words latex, polymer emulsion, polymer dispersion and polymer colloids are used interchangeable when talking about polymer dispersions. The particles must be small enough to flow together with the water between the smallest fibres. Upon drying the water evaporates and the remaining particles form a solid layer. Various latices exist, both natural (natural rubber latex for instance) and synthetic (PVC 'Polyvinyl Chloride', PP 'Polypropylene'). Whereas a PVC resin results in a stiff construction, a rubber latex-based composite is still flexible.

An interesting point regarding the availability is that in most countries with extensive fibre plantations also rubber plantations, see figure 4.1 exist. This gives the opportunity to domestically produce both NF composite ingredients.

### *Phenolic resins*

Phenolic resins have been the first synthetic resins to be commercially exploited. After a decreasing application in past decades, nowadays phenolic resins are more and more used. These resins combine low costs with flame retarding properties and are non-toxic. Phenolic resins result in stiff constructions.

Natural fibres in combination with these matrices result in state of the art NF composites.

## **4.2 Natural fibres in the composite industry**

Nowadays natural fibres form an interesting alternative for the most widely applied fibre in the composite technology, glass. The use of fibres like flax, hemp, jute or sisal in this industry so far is small since availability of a durable semi-finished product with constant quality is often a problem. Recent research and development have shown that these aspects can be improved considerably. Knowing that natural fibres are cheap and have a better stiffness per weight than glass, which results in lighter components, the grown interest in natural fibres is clear. Secondly, the environmental impact is smaller since the natural fibre can be thermally recycled and fibres come from a renewable resource. Their moderate mechanical properties restrain the fibres from using them in high-tech applications, but for many reasons they can compete with glass fibres. Advantages and disadvantages determine the choice:

### *Advantages:*

- + Low specific weight, which results in a higher specific strength and stiffness than glass. This is a benefit especially in parts designed for bending stiffness.
- + It is a renewable resource, the production requires little energy, CO<sub>2</sub> is used while oxygen is given back to the environment.
- + Producible with low investment at low cost, which makes the material an interesting product for low-wage countries.
- + Friendly processing, no wear of tooling, no skin irritation
- + Thermal recycling is possible, where glass causes problems in combustion furnaces.
- + Good thermal and acoustic insulating properties

### *Disadvantages:*

- Lower strength properties, particularly its impact strength
- Variable quality, depending on unpredictable influences such as weather.
- Moisture absorption, which causes swelling of the fibres
- Restricted maximum processing temperature.
- Lower durability, fibre treatments can improve this considerably.
- Poor fire resistance
- Price can fluctuate by harvest results or agricultural politics

In table 3.1 properties of the natural fibres are presented and compared to the properties of glass fibre.

### 4.3 NF composites, state-of-the-art

In the past two decades, growing interest for NF composites has resulted in extensive research. The driving forces are (i) cost reduction, (ii) weight reduction and (iii) marketing (application of renewable materials). Technical requirements were of less importance; hence application remained limited to non-structural parts for a long time. The reason for this is the traditional shortcomings of NF composites: the low impact resistance and moist degradation. Recent research however showed that significant improvements of these properties are possible, resulting in applications shown in figure 4.2 and 4.3. Experiences from NF composite applications in western countries can be applied in developing new products, suitable for agro-industrial countries. In the following section possible applications are discussed.



figure 4.2: A flax –reinforced car roof



figure 4.3: A flax –reinforced catamaran hull

### 4.4 NF composites for developing countries

In this part, possible applications of natural fibres as composites are discussed. Some of these products are already being manufactured, whereas others are the positive outcome of feasibility studies. All of these products require relatively easy manufacturing processes, suitable for production in developing rural societies.

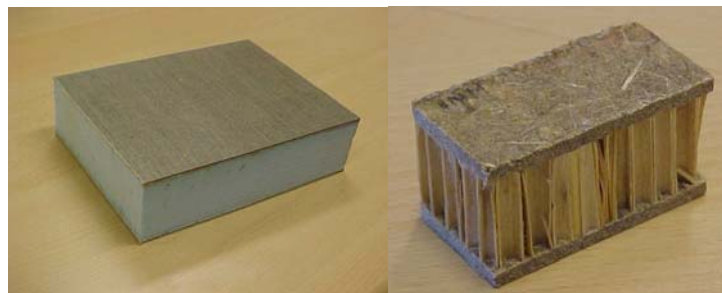


figure 4.4: Two natural fibre sandwiches.  
Left: foam core. Right: bamboo core

### Roofing panels

Natural fibres and resin material can be pressed into laminates that can act as skins of so called sandwiches (layered panel consisting of skins and a core), see figure 4.4. rural societies these panels can be used as roofing, see figure 4.5. Compared to corrugated iron roofing the natural fibre sandwich has improved thermal and acoustic insulating properties and doesn't cause zinc and rust pollution. Due to the use of local resources, the natural fibre sandwich is probably cheaper to manufacture. In comparison with traditional vegetable roofing, the sandwich is more durable. Similar panels can also be used as doors, tabletops and shelves.

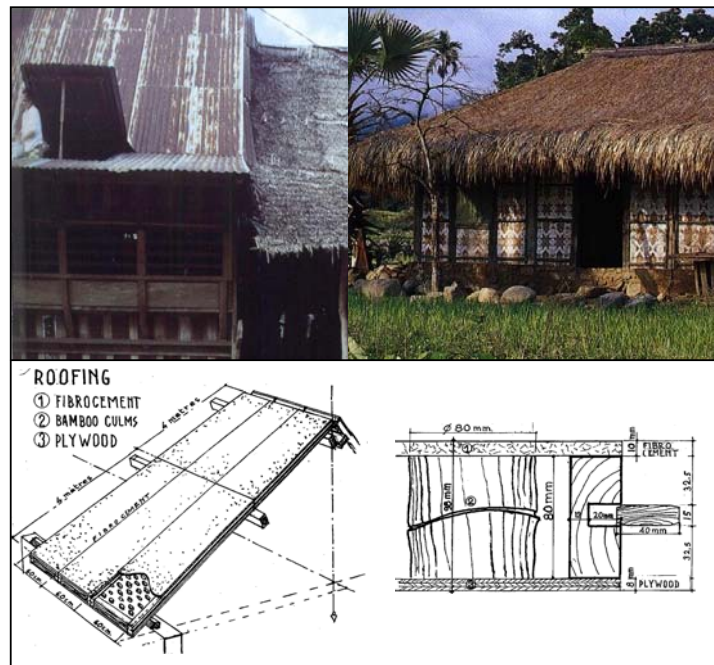


figure 4.5: Various roofing constructions. Top left: Corrugated iron roof. Top right: Traditional vegetable roof. Bottom: Natural fibre sandwich roof.

### Fluid container

Using cost effective filament winding equipment, see figure 4.6, reusable containers (figure 4.7) for transport and storage of liquids (water, beer, wine, fish- and soy-sauce) can be filament wound, see section 2.3, from spun natural fibres. Using natural rubber as resin, the container becomes “foldable-when-empty”. The thermal properties of the natural fibres keep the contents cool. The advantage over plastic or steel vessels is the environmental friendly design, the low weight and the reduction in transport- and manufacturing costs.

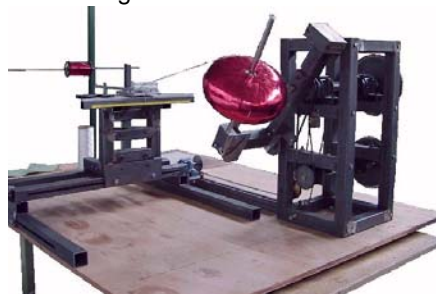


figure 4.6: Cost-effective filament winder



figure 4.7: Manufacturing of a Sisal storage container

### *Constructive bridge parts*

Using pultrusion technology, see section 2.3, natural fibre construction profiles can be manufactured at any length, see figure 4.8. A very useful application of these profiles in combination with the panels described earlier is a simple pedestrian bridge, see figure 4.9. This bridge is easily transported to remote locations due to its lightweight and withstands tropical conditions better than metal bridges. Due to the low weight, a less complicated foundation is required. Also window- or doorframes, scaffoldings and tubes can be made.



figure 4.8: Pultruded Sisal profile



figure 4.9: Bridge suitable for composite application

### *Small boats*

Small canoe-like boats, see figure 4.9 and figure 4.10, can be manufactured with vacuum techniques. These boats withstand corrosion better than metal boats and the low weight makes them easy to handle, both in the water and ashore. In addition, they are more durable than steel, wooden or bamboo boats.



figure 4.10: Composite canoe from Botswana



*Production in remote areas*

Typical of most developing countries is the living of people at remote places. Lack of proper infrastructure makes contact with the more densely populated areas very difficult. Due to the isolated character manufacturing of as many goods as possible takes place locally. However, still a lot of equipment and construction materials need to be “imported”, since the area is difficult to access, this becomes very expensive. Natural fibre composites can somewhat lighten this problem. Locally grown fibres can be turned into composites with “imported” resin. Transporting this resin as a powder, using rainwater for impregnation of the fibres, results in bulk transport, which significantly decreases costs. Having all ingredients at hand, a large variety of additional products can be locally manufactured with simple manufacturing processes.

## 5. Composite technology transfer

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In this chapter a way to transfer composite technology for application in rural industry is discussed, as well as the general contents of transferring projects and the targeted goals.

### 5.1 Development of rural industries

Based on century-old knowledge, passed on through generations, the rural industry shows no significant changes. The same products are made these days, using the same techniques, as thousand years ago. In previous centuries there was no need in developing this sector, it formed a stable part with its surrounding environment. In the past century, the improved global infrastructure resulted in contact between the unchangeable rural industry and the rapidly evolving modern industry. The stability disappeared and the need arose for changes. Never having had the need for changes, the rural industry has difficulties implementing changes by itself, for the following reasons:

#### 1. Family character

Rural industry's primary objective is production of all kinds for the family in first place and for the local market in second place. Money earned is directly used to buy additional family needs and is not used for innovation as is usually done in enterprises aiming at economical profit. In other words there is no money available to develop and purchase new equipment. Besides this, since everyone participates in this process, no manpower is available for research and development of improved rural technology.

#### 2. Oral distribution of knowledge

Most knowledge generated was passed on through myths, tales and plays. Usually, they were not written down. The advantage of a text is that it can be easily modified. There is no need to memorise everything since one can always reread the text. In contrast, these oral tales have to be thoroughly memorised since rereading is not possible. As a consequence all knowledge is firmly embedded in the mind of society, becoming hard to change.

#### 3. Isolation

Although infrastructure has improved significantly between urban and rural areas, it is often very difficult for rural areas to apply developments achieved in the city areas. On the one hand, technology improvements are aimed at application in urban areas and are not adapted for use in rural industry. On the other hand, universities and technology institutes are still not easily accessible for rural society.

Without aid from outside, rural industry will most likely never change. Transfer of technology discussed in this chapter is an example of outside help.

### 5.2 Technology transfer

Successful agricultural societies can create more growth and prosperity by encouraging industries to manufacture and trade goods fulfilling the local needs. In the wake of these activities even more growth and prosperity can be created by the distribution and commerce of viable services and goods. Nowadays in most developing countries starting manufacturing and trade activities are generally speaking based on importing industries and technologies which are almost obsolete in their former and wealthy home countries. It is a rational way to extend the commercial life of activities by finding (market) regions with lower costs (labour and taxes) or geographic attractiveness with respect to marketing and regulations. However is the import of technologies fighting on top of the technology curve a smart approach for developing countries which are in possess of a fast growing and hardworking population, ambitious and having the possibility of getting top education?

Leaders of such countries can better stimulate strategies of becoming entrepreneurs in novel activities which fit the culture with respect to the basic resources capabilities and needs. Starting local niche markets can grow to global size if intellectual and entrepreneurial spirit and capabilities are present, first to fulfil the needs of the domestic market and when settled and successful, to find opportunities for export or exchange. Of necessity is a fundamental knowledge of the novel technology. The transfer of novel fundamental knowledge, which can be further expanded in developing agro-industrial societies, leads to a more durable transfer of technology.

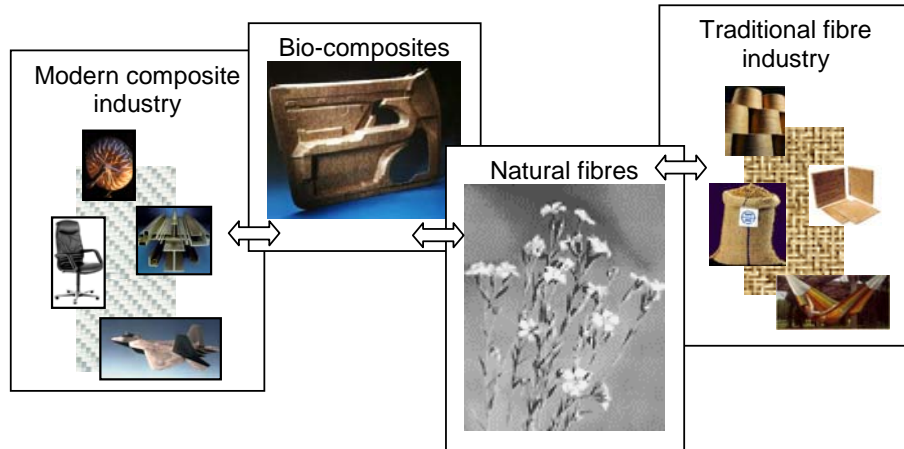


figure 5.1: Natural fibre as link between modern and traditional industries

Such a durable transfer of NF composite technology can be achieved when using natural fibres as transfer-link (figure 5.1) between the modern western composite industry and the traditional fibre industry. Since the fibre industry is already present, adding composite technology results in the development of the entire production chain for NF composite products, consequently maximising the benefits:

- Growing of the materials
- Processing of the materials
- Design of NF composite products
- Manufacturing of NF composite products
- Use of NF composite products

It has to be said however, that before any transfer of technology can be executed, all parties involved must be aware of the constructive potential of their natural fibre resources. In other words, the first step is to identify the opportunity. This report will hopefully contribute in raising awareness for application of natural fibres in NF composites. In this chapter the benefits of technology transfer, step 2, along the natural fibre link are discussed.

### 5.3 Benefits of the natural fibre link

Four benefits are obtained using the natural fibre link to transferring composite technology.

#### 1. Matching technology

Figure 5.2 shows schematically the development of composites in the western world. Parallel to the increasing level of technology, costs of materials and manufacturing raise, as well as complexity of the processes. The state of the art composite technology based on the reintroduction of natural fibre matches perfectly with the still widely used traditional technology of agro-industrial societies.

Instead of chasing the West, following the same development going through the phase of ever increasing material prices, a small step in opposite direction of the development circle results in an immediate jump to state of the art technology whilst staying in the area of the inexpensive natural fibres.

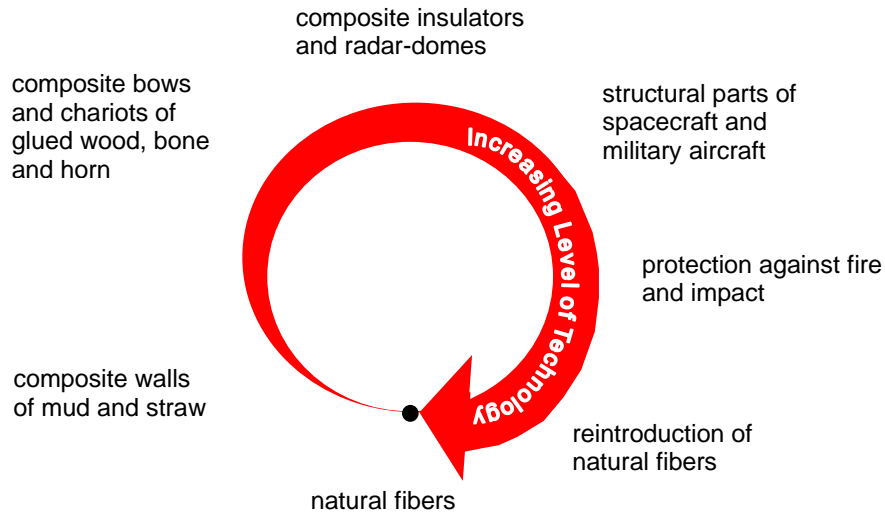


figure 5.2: Development circle for the composite technology

## 2. Cultural compatibility

Processes developed in the western world are optimised according to a background of western morals and values. A freshly transferred technology might not at all prosper in an environment with completely different morals and values. When transferring composite technology through the natural fibre link, one is forced to adapt the processes to fit the already existing natural fibre industry. Adaptation automatically reduces the cultural gap, consequently increasing the chances of successful implementation.

## 3. Natural resources

Most developing countries still have a large agricultural based character, with an accent on rural societies. A large part of the country is occupied with fields for edible or industrial crops, which are exploited by an enormous work force. This in combination with the traditional agricultural knowledge and the fruitful climate often results in multiple harvests per year. In other words, the crop producing potential, including natural fibres, of these countries is high. Although climate differs from country to country, the variety in natural fibres is broad, resulting in the fact that in every climate zone (with the exception of the extreme dry- and cold climates) at least one fibre crop can grow. For instance Sisal can be grown particularly in the drier African region, whereas Flax like crops are more found in Asia.

## 4. Low investment costs

Production of synthetic fibres, followed by weave, mat and prepreg manufacture, are based on machinery and high investments. It takes place in the industrialised countries, so for most countries it is an imported product to be paid with hard dollars. The production of natural fibres however, can be carried out by manpower and traditional know-how. In those countries, like in South East Asia and Africa where natural fibres can be grown fast and at low cost, the material resource is in own hands. Importing of non-domestic materials, like glass fibres, at high prices in foreign currency can be avoided. In addition, the lower investment costs and the

linked reduction of financial risks are important arguments in persuading potential financiers. The transfer projects will be more readily financed and local entrepreneurs will be more willing to implement the generated knowledge in the society. In addition, the already existing tendency of clustering will result in a reduction in overhead costs.

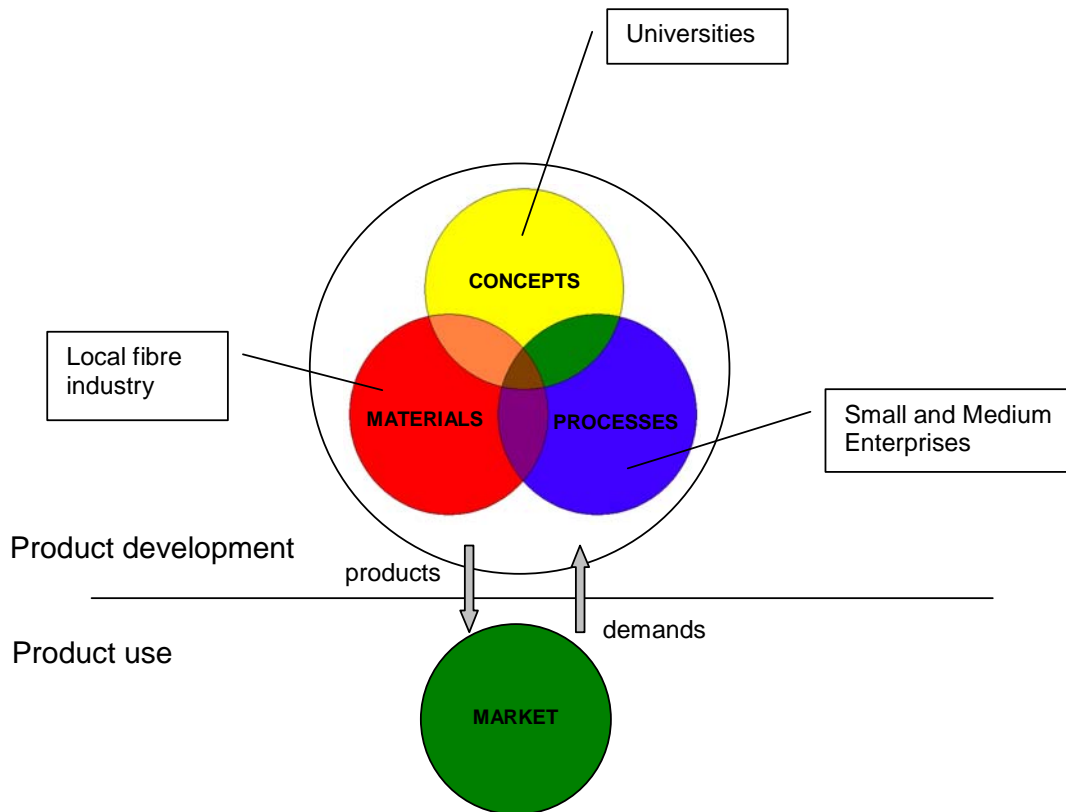


figure 5.3: Product aspects

#### 5.4 Project requirements

The aim of transferring a technology is to build a self-sustaining technology. At the end of the courses the FAO member country should be able to not only manufacture certain products, but should also be able to modify and develop products itself. Therefore, all aspects of product development should be targeted by the project:

- Concept development
- Material fabrication
- Product manufacturing
- Market
- Regulations

These four aspects are intertwined. As mentioned before, concept, materials and processes form an integrated design. The market offers product opportunities and creates demand, see figure 5.3. To protect manufacturers and customers a regulatory system has to be created. In the next paragraphs the five aspects are discussed.

### *Concept development*

To fully exploit the possibilities that composites offer, education at Universities and other technology institutes is required. Sufficient knowledge of materials and manufacturing processes is required. Concerning materials, one requires the knowledge to quantify properties and to use these properties in the best way. Processes involve the right choice of machine settings, for instance machine speed and temperature. To apply this knowledge design tools and mathematics need to be mastered. Gradually a feeling for composite application will develop. With the aforementioned, one should be able to develop optimised composite products made of local materials for the local market.

### *Material fabrication*

As materials suppliers, very little training is required since this segment is already well developed. The only required training might be to produce spun yarns with a variety in thicknesses and fabrics with different weave patterns. It is also important that as sale of composites increases, local farmers are persuaded to increase fibre production to meet the demand. A point of attention is the fact that today the grown fibres and the related processes are optimised to produce an optimum fibre for textile applications. For growing fibres for composite applications, a different variety of fibres and different way of processing might be more suitable.

### *Product manufacturing*

Whether products will be manufactured in individual enterprises or at the fibre plantations itself depends on the local situation. Fact is that machines are required and operators need to be trained. When thinking of manufacturing products in developing countries, one has to take three things in account:

1. Local financial capabilities are rather low, making it hard for companies to invest in expensive western equipment.
2. The tropical climate and other environmental differences hinder the proper functioning of western equipment.
3. An infrastructure to check and maintain modern western equipment usually doesn't exist.

With these three points one comes to the conclusion that transferring modern (high-tech, expensive) equipment to developing countries is not the best way to start production of NF composites. Like the products aimed for, the manufacturing processes and equipment need to be adapted to the local situation as well.

The equipment must have the following properties:

- Low-investment costs
- Easy to build (local manufacturing of equipment)
- Easy to maintain and repair
- Easy to operate
- Must withstand tropical environment
- Must result in products with sufficient quality

To reduce investment costs and to allow the machine to be used by as many people as possible, simple machines need to be derived. These machines are the low-tech variant of already existing computer-controlled, multi-purpose, complicated machines used in the western world. The simple machines are easy to build, maintain and operate and to reduce costs the product variety that can be manufacture on a single machine is kept low. Figure 4.6 shows a cost-effective filament winder at Delft University of Technology.

### *Market*

To create a market for the composites, two things are required:

1. Companies to sell these products. Either new enterprise can be found or existing ones can add composites to their inventory.
2. Demand for composite products.

The focus should lie on familiarising the society with composites and convincing them to use composite products. Prototypes and introducing products, see section 4.4, can best do this. The difficulty lays with the fact that the cost price of composites often exceeds the price of similar products but that due to a more durable design cost reduction is achieved over a longer period. The consciousness has to be raised to consider long term costs.

### *Regulations*

A governmental controlled institute has to be erected to create regulations and to see whether the rules are followed. Regulations should concern:

- Copyright protection to protect investments
- Product quality too protect customers
- Working conditions to protect employers

## **5.5 Short term goals**

### *Increase knowledge*

On short term, basic knowledge should be developed, which forms the basis from which FAO Member countries can develop its own low-cost composites. The level should also be sufficient high to participate in international composite development and exchange of master and Ph.D. students with foreign Universities. In the wake of the increasing knowledge a regulatory institution has to be erected.

### *Familiarise society*

Introduction of composite products in the society is required to create a market.

### *Improve living conditions of rural society*

Since the traditional fibre industry forms the pillar of the composite industry it should be strengthened. Selling fibres and/or composites generates money that can be used to improve the living conditions of the rural society.

## **5.6 Long term goal**

### *Development of large-scale rural based composite industry*

Gradually expanding the local market towards national and possibly international size, the long-term goal will be achieved: A self-sustaining full grown NF composite industry incorporating design, manufacturing and trading of composites guarded by regulations and an international co-operating educational system to pass on and increase knowledge.



## 5.7 Future prospects

With a developed NF composite industry, it is only a small step towards a modern (synthetic fibre based) composite industry. With the experience from the NF composites, products don't have to be copied from western countries, but new ones specifically design for the domestic situation can be derived. An example is the development of a carbon- or glass fibre gas tank for domestic use. A lot of developing countries don't have a gas distribution network and use heavy steel tanks instead.



## 6. Context for industrial development of composites

Natural fibre composites (NF composites) offer benefits to the society from different points of view. In this section the benefits are regarded from an Economic, an Ecological and a Technical point of view (E.E.T., see figure 6.1), for various parts of society.

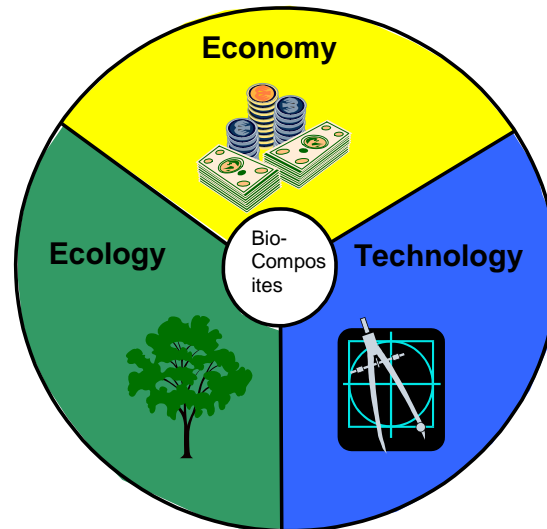


figure 6.1: E.E.T. (Economy, Ecology & Technology)

### 6.1 Government

By investing in NF composites, a government obtains a piece of state of the art technology. NF composites distinct themselves from other technologies due to their complete character. Often only the manufacturing aspect of a technology is transferred to utilise the low labour costs. Just enough knowledge is given to manufacture products for the western world. NF composites connect to the traditional local fibre industries and find direct application in rural societies. Due to these two facts the entire product development cycle can be implemented, including material supply, product development and –manufacturing. Due to this complete character and a domestic market, a larger money flow and more employment is created than with another imported technology. In addition, money and jobs are immediately distributed over various layers of society.

Since the entire product development cycle is in domestic hands, international relations can be easier established in terms of export contracts, co-operative research contracts or even educational contracts. Due to the complex technological character of NF composites, it is very hard for neighbouring countries to copy the technology without co-operation. Having an exclusive technology at its disposal, a country strengthens its regional position.

Besides these short-term benefits also an important long-term benefit is obtained due to the sustainable character of NF composites. Due to the use of biological degradable materials, NF composites are relatively environmental friendly. In addition, the lightweight aspect reduces fuel consumption during transport, which brings both environmental as economical benefits.

Since the government represents the entire society, advantages mentioned hereafter benefiting specific parts of society also benefit the government.

## 6.2 Research institutes

Universities, laboratories and research institutes take in high tech knowledge, which can be domestically utilised. Output consisting of research results and trained students can directly be applied in society. Due to this social relevance governmental support can be expected. The fact that the knowledge is focussed on the particular situation of the domestic fibre industry results in the fact that trained students will always remain linked to their home country, preventing a “brain-drain” to the western world.

Composites are a hot item on international scale. Obtaining the technology brings international recognition and opens the door to international projects as co-operative research and exchange of students, Ph.D. candidates and experts. These projects raise the level of expertise and output for all parties involved.

## 6.3 Rural society

Due to the coupling with the traditional fibre industry, the rural society will benefit the most of the NF composites. Since the fibres are involved from the start in the development of products, benefits for rural society start immediately. Since material production (agriculture) and product manufacturing (rural industry) both take place within this society, not only the demand for their natural fibres raises, but also significant value is added. No matter what the size of the NF composite industry will grow to, the natural fibres will always form the irreplaceable foundation. Another advantage is that due to the high level of traditional knowledge, the NF composite industry is open for every member of the rural society and is therefore an important creator of jobs for both Small Scale and Cottage Enterprises (SSCE) and Medium and Large Scale Enterprises (MLSE). More information regarding these enterprises is given in section 3.3. Since the initial aim is to manufacture for local markets with local materials, within rural industry SSCE will benefit the most.

In addition to economical benefits, NF composites also have consequences involving improvement of working conditions. In most FAO Member countries conditions in workshops are appalling. In many cases there is no ventilation on the work-floor, little protective clothing and masks, inferior equipment, no special storage of chemicals and waste material, low wages, long working hours, etc. Often work is performed by women and children. This is of course a general issue in many third world countries and it is something that is difficult to solve without financial support from outside. It is clear that many things in health and safety of employees can be improved through education and investment but this is costly to implement, and employers shall only make changes if somebody else pays for it or are forced to do so by government measures. Although NF composites don't solve these problems, they somewhat reduce them. Manufacturing composites of natural fibres involves “friendly” materials and processes. Processes are mainly mechanical and contact with toxic chemicals is little. Moreover, manufactured products are relatively light, reducing the physical aspect of the labour.

Region	Tonnes	Percentage
Far East	770.000	41.6
Russia and Kazakhstan	470.000	25.4
Middle East and India subcontinent	212.000	11.5
Central and South America	205.000	11.1
Africa	72.000	3.9
Europe	60.000	3.2
North America	60.000	3.2
Total	1.849.000	100

Source: The Asbestos Institute

table 6.1: World asbestos consumption in 1999

In general, NF composites can replace asbestos in constructions, a material well known for causing cancer. World production of asbestos amounts to approximately 1.8 million tons per year. The major producing countries are Canada, the former Soviet Union, South Africa, and Brazil. As asbestos consumption in industrialised countries decreased, asbestos exports to the third world increased, see table 6.1. Experts are afraid that many workers and residents might be killed by asbestos.

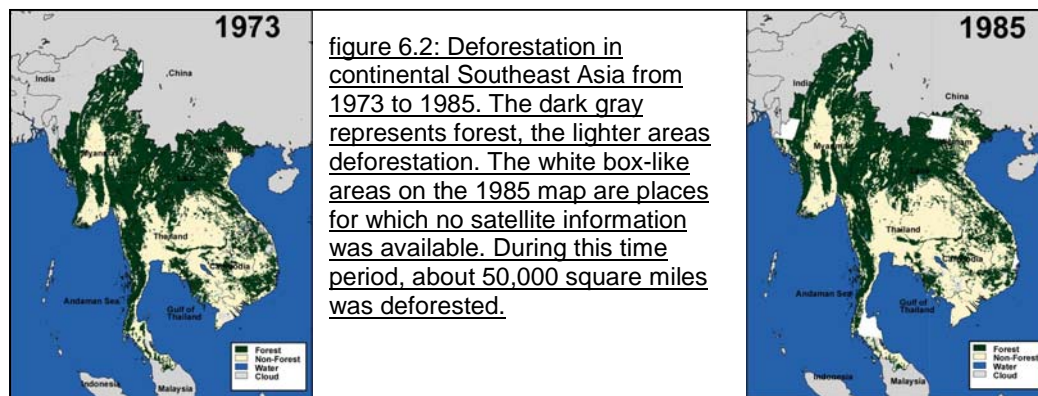
#### 6.4 Enterprises

Entrepreneurs of SSCE and MLSE are offered the opportunity to exploit NF composite products. The short trajectory from raw materials to the market in combination with the relatively easy to perform manufacturing techniques result in low investment costs, whereas the products are already applicable at locale markets. Since the market for NF composites is yet to be discovered, new companies can already capture a prominent position. Although often copyright protection is absent, the freshly obtained position is guarded by the complexity of starting up a manufacturing line. Besides supplying the locale market, export is a future option.

NF composites are not only interesting for domestic SMEs but also for foreign ones. Through international co-operation between foreign companies and companies at the source of natural fibres and applications, the market can expand opening doors for new-to-develop applications.

#### 6.5 Women

Being largely represented in the Small Scale and Cottage Enterprises as both manufacturers and company-managers, women will benefit directly from the economical possibilities of NF composites. With the upgrading of indigenous technology and the exploitation of successful enterprises, women will both increase their ability to generate income and will finally receive the recognition they lack in most developing countries. Although this attention will mainly be focussed on female entrepreneurs in the fibre industry, women involved in other rural activities will also find new attention. Generally the position of women in these countries will improve.



#### 6.6 Nature Conservation

NF composites can play an important role in preserving the indigenous forests. The forests of most FAO Member countries are rapidly being cut down for timber, see figure 5.2 and figure 6.3. Although extensive reforestation programmes are initiated, the balance existing in century old eco-systems remains disturbed, threatening the environment and the conservation of the biodiversity of plants and wildlife.

NF composites form an important substitute for timber-wood, reducing the need to cut down trees. Compressed NF composite panels and extruded profiles can substitute wooden board and beams as construction elements, but also single step manufactured constructions can replace their wooden counterpart.

Although indeed forest has to be felled to make room for plantations, it has to be kept in mind that they provide a harvest multiple times per year whereas indigenous forests can only be cut down once. Moreover, before new plantations are planted, attention has to be given to raise the yield of existing plantations, hence saving the forests.



figure 6.3 Deforestation for timber-wood

Another environmental issue is the output of the NF composite industry in the form of sustainable products. A sustainable product fulfils the need of a current generation without compromising future generations to fulfil their needs [Brundtland, 1987]. In concrete terms, a more sustainable design uses up less materials and/or energy during manufacturing, use and disposal, leaving more options over for future choices. Therefore, sustainability takes in account the entire product trajectory. The use of natural materials and mainly mechanical processes raises sustainability in the manufacturing stage and during disposal. The lightweight character of the products reduces fuel consumption during transport.

Preservation of the variety of resources increases due to the improvement of the position of women, which can be explained as follows. Traditionally, women are engaged in the production of food for the family, as part of the household activities. Throughout history, they developed and improved their knowledge regarding the choice of seeds and the growth of crops. Since the main purpose of this type of food production is survival of the family, women learned to increase the variety in crops to account for fluctuating natural circumstances. Growing different crops with a large variety of properties means that in case of extreme drought at least one crop will survive to nourish the family, whereas in case of extreme rainfall another crop will provide food. By increasing the chances of survival of their family, women simultaneously contributed to the preservation of floral biodiversity. This biodiversity is threatened by decisions made by men, who traditionally tend to a more economic approach of agriculture. To increase income it is usually more profitable to reduce crop variety. Since in most developing countries men dominate society, crop variety gradually reduces. By improving the situation of women, their influence on deciding which crops to grow increases, hence the biodiversity will remain.

## 7. Example projects

Past and present projects regarding the introduction of natural fibre composites (NF composites) in developing countries are discussed in this chapter. These projects can be used as an example for setting up future projects. Already some knowledge is being transferred in past projects and consequently the number of companies in developing countries dealing with natural fibre composites is increasing. Expertise at research institutes is increasing everyday and due to the execution of projects in co-operation with local companies, experience is gained in the development in marketable products.

### 7.1 Past projects

#### *Rural Industrialisation project India 1998-1999*

The Indian Ministry of Small Scale Industries and Agro & Rural Industries started in 1998 a program to develop rural areas by renovating the traditional coir industry. Emphasis was given on fibre processing, machine and product development and service extension. Rural society was trained to increase quality and revenue of the traditional fibre industry by developing new products and machines and expanding the market without the loss of jobs. An inexpensive motorised spinning ratt was used for training and production. The distributed machines produced yarns for the production of for instance geotextile (textile to prevent soil erosion, see figure 7.1.). At the same time entrepreneurship was promoted, aiming at new entrants and educated unemployed from within the rural society. The final part of the program was the promotion of coir products. In the following years export value of coir products raised with 11%.

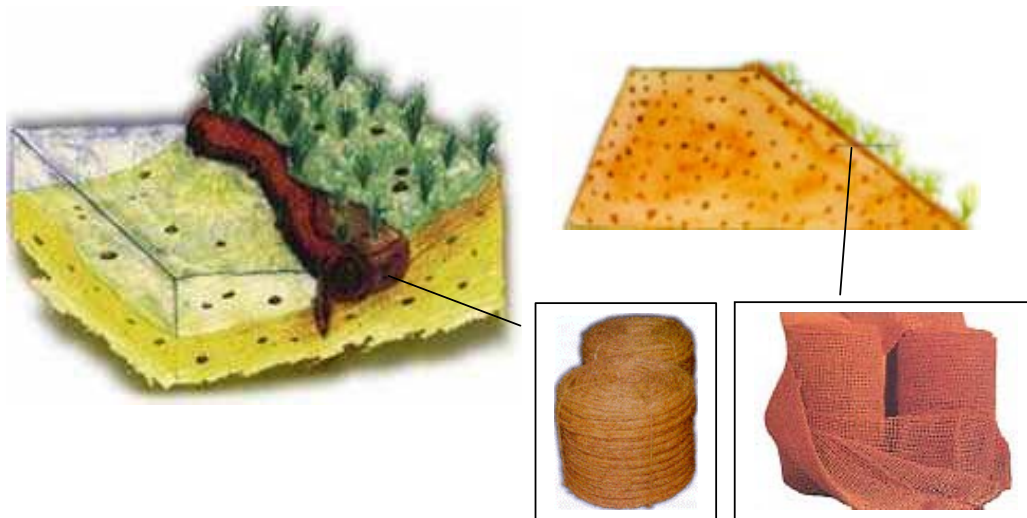


figure 7.1: Coir geotextiles

Although this project isn't about NF composites, it is one of numerous projects searching for new natural fibre based products. In these projects, NF composites are often left out, simply because people are still unaware of the potential natural fibres have to offer as construction materials. Hopefully due this report, NF composites will form a part of every future project searching for new natural fibre applications, or become part of follow-up activities of existing projects.

### *Low cost water system project, Guatemala*

Early 90's, the Centre of Lightweight Structures TUD- TNO, The Netherlands, executed a United Nations project in Guatemala for the local manufacturing of primitive composites. Starting point formed Guatemala's enormous jute resources. With trucks water-soluble resin-powder (modified urea-formaldehyde) was transported to remote areas, where rainwater was used to impregnate the locally manufactured jute textiles, see figure 7.2. Large PVC balloons were used as mandrel to manufacture water tanks and latrines, see figure 7.3. After the project, production of these products for local use continued successfully.



figure 7.2: Hand lay up of jute on a PVC balloon



figure 7.3: Jute latrine

### *Vietnam Composites Project 1999*

In 1999, the Faculty of Aerospace Engineering (Delft University of Technology, The Netherlands) and the International Training Institute of Materials Science (Ministry of Education and Training, Vietnam) initiated a program concerning the transfer of composite technology to Vietnam, the Vietnam Composites Project 1999. This project formed the first step in transferring composite technology to Vietnam with the objective to investigate feasible applications for composites, to establish co-operation with Vietnamese industry and Universities, and to start a training program applying on a group of Vietnamese students. The outcome of this project can be summarised as follows:

- Due to a general low technical level and resulting poor image of composite technology in Vietnam, the requirement occurs to introduce higher level technology serving the aim of convincing people of the value of high-tech investments in this field. Complex applications will also prevent copyright violations.
- To ensure continuation of the proposed program, industrial activity in the field of higher-level composite technology is vital. Due to a pragmatic business environment based on short-term profit, existing companies seem not suitable for fruitful co-operation. New companies have to be started up to serve the Vietnamese market.
- A different market may be found in the field of natural fibres. Vietnam has a potentially large supply of these fibres, which have until this moment only found utilisation in clothing. Possibilities exist to expand the application field towards structural application, as is happening in Europe.
- Education for students was given in the English language, but the lack of English-listening/speaking abilities of most students was a barrier for full understanding of the course.

Based on the outcome of the pilot-project, a second project is initiated: ABC 2001, see section 7.2.

## 7.2 Running projects

### *Applied NF composites 2001, Mission Vietnam*

After a pilot-project, mentioned in section 7.1, a second project targeting natural fibre composites for the locale market is initiated in 2001: Applied NF composites 2001, Mission Vietnam (ABC 2001). The final goal of this program is to develop a NF composite industry in Vietnam. The need for this is high since Vietnam's industrial development is being held up by the following phenomenon; to develop a type of industry already existing in her region is more costly than to import products of this same industry from neighbouring countries. With the aforementioned kind of industry, Vietnam will be able to increase her export capabilities resulting in a strengthening of her economic and technological position being a property consequently stimulating the entire region. Involved parties are the Faculty of Aerospace Engineering (Delft University of Technology, The Netherlands) and the International Training Institute of Materials Science (Ministry of Education and Training, Vietnam).

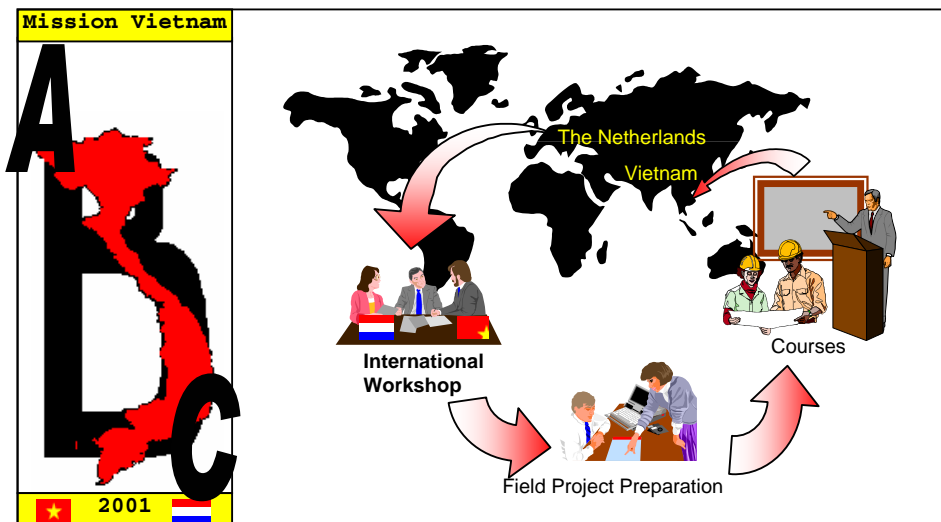


figure 7.4: ABC 2001 structure

On short term, the knowledge on various manufacturing technologies will be increased up to a sufficient high level for Vietnam to develop its own low-cost composites and to become a valuable companion for further research in co-operation with Delft University of Technology and local industry. For the latter, a student and Ph.D.-candidate exchange program will be initiated and local industry will be approached. Manufacturing of suitable natural fibre composites for the local market will start on the plantations, with the aim to raise demand for these fibres and to improve the situation of the small-scale producers of this part of the agricultural society. In the wake of the increasing knowledge a regulatory institution has to be erected. Gradually expanding the market for the natural fibre towards a national and possibly international size, the long-term goal will be achieved: A Vietnamese self-sustaining full grown composite industry incorporating design, manufacturing and trading of NF composites guarded by regulations and an international co-operating educational system to pass on and increase knowledge. Although in modern countries the composite is a Hi-Tech industrial branch, small-scale farmers are targeted, forming an important pillar of the Vietnamese composite industry.

Before any technology is actually transferred a workshop (i) will be organised in Vietnam in the beginning of 2002, see figure 7.4. Participants will consist of experts of The Netherlands and Vietnam in the field of composites, natural fibres, economics and development aid, completed by representatives of the Vietnamese government, industry and agriculture. The aim is to discuss the best way for the technology transfer, consequently maximising efficiency. Based on the outcome of this workshop the first field projects (ii) can be prepared. The aim is to start courses in Vietnam at the end of 2002. The project will run for 3 to 4 years.

#### *Sisal: Agriculture business in north-eastern of Brazil*

In 2002, a project will be executed by SEBRAE (Serviço Brasileiro de Apoio às Micro e Pequenas Empresas) in Rio Grande Do Norte, Paraíba and Bahia in the north-east of Brazil. The main objective of this project is to obtain new sisal fiber applications with increased added value. The focus areas are geo-textiles and composites for the automotive industry and civil building. Besides the design of the related products, bringing them to the market forms an important project part. Main beneficiaries are rural population in producing areas in Brazil. This population will get the follow benefits: (i) new jobs; (ii) technological procedures; (iii) new market opportunities.

#### *Composite Applications using Coir Fibres in Sri Lanka*

In an era where natural fibre based products gain increasing market acceptance, the coir industry in Sri Lanka seems to loose international market share. Very limited break through and value added products have been internationally launched in the past decades from Sri Lanka. In order to increase the market penetration of coir in the present industries, and also to penetrate new industries, in addition to traditional products, new and innovative technologies are needed.

The present project aims to assess the suitability of coir fibre for the use in presently available composite technologies and thereby determine the potential for marketable products. It is hoped that in this project a real synergy between applied R&D and International Marketing orientation will lead to commercially acceptable results. This project is an initiative of:

Sri Lanka: Jafferjee Brothers – Zylyon International b.v., Hayleys Group, The Industrial Technology Institute (ITI)

The Netherlands: Delft University of Technology

#### *Sisal Fibres from Madagascar in New Composite Applications*

Sisal fibre is grown in large quantities on Madagascar. Applications are cordage, ropes, car-interior panels, geo-textile and paper. Today, two problems are faced: these sisal products are losing their market to artificial materials, and secondly, sisal is mainly exported as raw material with very low added value. Component manufacture takes place outside Madagascar (Europe) Competition with other sisal suppliers is strong and profits are low.

With the right know-how on processing technologies, sisal composites can easily be introduced in developing countries without the need of large investments. At the Delft University three of those low-investment technologies have developed, being the vacuum injection technique, LFT pressing and filament winding. These techniques will be further optimised for sisal fibre composites, resulting in directly applicable products. The new applications that sisal composites can offer and the fact that components instead of raw material can be exported will both have a positive impact on the competitiveness of sisal. Besides Delft University of Technology also SIFOR, Societe du Sisal Malgache, Domain Pechpeyrou, Antananarivo University, the Malagasy Institute of Technology and Syndicat de Producteurs de Sisal de Madagascar are involved.

## 8. Conclusions

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- Due to the wide variety of available manufacturing processes, each resulting in their own characteristic products, the design possibilities for composite products are numerous. Consequently, a composite product and its manufacturing process can be chosen to best fit the developing rural societies in which the products will be made and used. Besides the technical feasibility, manufacturing of composites becomes also financially feasible when using domestically grown natural fibres in combination with simple manufacturing processes.
- Within the composite industry, NF composites form an interesting group. Bio-composites often lead to a reduction in weight and costs and are more environmental friendly. For these reasons the popularity of these composites is increasing in the western world and already a significant amount of scientific knowledge is generated.
- The fact that most developing countries still strongly depend on their rural sector, which supplies the raw materials for NF composites, gives a good link to transfer the technology, the so-called natural fibre link. The link is strongest when making NF composite part of the rural industry.
- Using the natural fibre link to transfer the technology shows 4 advantages:
  1. The modern technology largely matches the traditional fibre technology
  2. Due to this matching the cultural differences are decreased
  3. The natural materials are domestically grown and expensive import of synthetic materials is not required.
  4. The required investment costs are relatively low.
- A sustainable development approach is pursued, meaning that after the introduction of the technology, the receiving country is capable of independent further development. To facilitate this development, all aspects of bio-composites must be present in society:
  1. Concept development
  2. Material fabrication
  3. Product manufacturing
  4. Market
  5. Regulations
- Knowledge for concept development requires to be transferred to Universities to fully use all advantages composites provide. Manufacturing of materials and products will be done in rural areas. To reach the domestic market, single Small Scale and Cottage Enterprises (SSCE) need to be founded. When aiming at Small Scale and Cottage Enterprises all aspects of the NF composite industry remain in domestic hands, whereas future options for export remain open. A regulatory framework has to be erected on governmental level.
- When starting up a natural fibre composite industry, the benefits can be summarised into Economical, Environmental and Technical, as follows:
  1. The entire production chain can be developed, maximising the benefits for the targeted country in terms of money and employment.
  2. Due to the interest on natural fibre composites in western world, targeted countries can participate in co-operative research, participating in globalisation. This is increased when also the export market for natural fibre composites is aimed at.
  3. Environmental benefits can be found in the sustainable character of the materials used and the fact that NF composites can replace tropical hardwood.
  4. Working conditions are improved due to the friendly character of the fibres (no skin irritation) and the lightweight property of the products, reducing the physical strain of the work. The latter benefits women largely, since they are well represented in the rural industry.



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Site of the Structures and Materials Laboratory of the Faculty of Aerospace Engineering, Delft University of Technology.

[www.clc.tno.nl](http://www.clc.tno.nl)

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Site of NASA – Earth Observatory





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