Natural Fibres and the BIOCOMPOSITES INDUSTRY

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Kenaf long fibres used for biocomposite industry.

Natural fibres have played a major role throughout human history. Even the earliest humans learned to use these resources to make shelters, cook food, construct tools, make clothing, paper, and produce weapons. Collectively, society learned very early the great advantages of a resource that was widely distributed, multi functional, strong, easy to work with, aesthetic, biodegradable, and renewable. Compared to synthetic fibres made from glass, carbon and steel, natural fibres have a high aspect ratio, high strength to weight ratio, relatively low in energy conversion, and have good insulation properties (sound and thermal). The fiber structure varies depending on the type of fibres, for instance hemp has hollow structure, whilst kenaf has a woody inner core. Some might consider part of these properties as problems, such as biodegradable and combustible, but these features provide a means of predictable and programmable disposal not easily achieved with other resources.

Early manufacturing entrepreneurs must have started off using naturally occurring composite materials such as wood, horn, sinew, bone and plant fibres before moving on to metals and ceramics. It is somewhat later in history that the fibre reinforced resin matrix composites make their appearance. The history of biocomposites has dated back since 500BC, where Athenian Hoplites (now Greece) used resin bound linen to make the Lineothorax, a tough and light cuirass type body armour. Across the world, in late medieval Japan, lacquered Chinese water buffalo hide and papier-maché were used for similar effect. Some 3,000 years ago in ancient Egypt, clay was reinforced by straw to build walls. These inventions continued to invade the world until today where its' effects can still be seen. One good example of such invention is the Great Wall of China which was constructed in the VI century that owes it's durability to the addition of rice flour to the clay as binding material. Small particles of the rice flour ensured the durability of the biggest human construction until today.

The history continued where in the late 1930's, Henry Ford used soya oil to produce phenolic resin for making wood filled composite material for car bodies. Since then " a bushel of soya" went into every model of Ford, including spun fibre for upholstery. Meanwhile, in the U.K, a flax reinforced Spitfire fuselage was made in the 1940's at Duxford, Cambridgeshire. At about this point, the modern civil composites industry started off a curious combination of high-tech aeronautical applications and minimal capital outlay contact moulding methods for the manufacture of large low production volume mouldings such as boats and sports car bodies. Since then, the focus has shifted from natural fibre reinforcements to artificial - mostly glass in the first instant, and cold cure polyester resins. The development story of modern composites industry starts here, with artisan methods making way for automated manufacture, and all the while, the parallel development of resin chemistries, fibre sizes and architectures, all focused on a relatively small range of resins, mostly epoxies, polyesters, and phenolics, and a small range of artificial fibres such as

Kenaf long fibres in reel form.

Moulded kenaf plastic composite for car components.

glass, carbon and aramid. During this pursuit of ultimate mechanical properties and manufacturing convenience, natural fibre composites fell into abeyance.

THE REVIVAL OF NATURAL FIBRES

What we might call the modem wood composite industry had its beginning in the late 19th century in Switzerland. A type of glue laminated beam was made for an auditorium using a casein adhesive. The world plywood industry started around 1910, the particleboard industry in the 1940's, the hardboard industry around 1950, and the medium density fiberboard (MDF) industry in the early 1960's. Later in history, the resin matrix bonded fibrous reinforcement articles (which are presently known as biocomposites) make their appearance. A biocomposite material is formed by a combination of a matrix or resin and a reinforcement of natural fibers (usually derived from plants or cellulose). Biocomposites materials have wide-ranging uses from environment-friendly biodegradable composites to biomedical composites for drug/gene delivery, tissue engineering applications and cosmetic orthodontics. They often mimic the structures of the living materials involved in the process in addition to the strengthening properties of the matrix that was used but still providing biocompatibility, e.g. in creating scaffolds in bone tissue engineering. Biocomposites are characterised by the fact that:

- the petrochemical resin is replaced by a vegetable or animal resin, and/or
- the bolsters (fiberglass, carbon fibre or talc) are replaced by natural fibres such as wood, kenaf, hemp, flax, sisal, jute etc.

Professor Roger Rowell from University of Wisconsin, Madison, USA estimated that there are over 4 million dry metric tons of natural fibres available in the world. Natural fibres can be produced from different parts of plant such as bast, leaf, seed, fruit, wood, grasses and reeds, depending on the types of plant. These plants are rich in cellulose which is the building material of long fibrous cells, a natural polymer with high strength and stiffness per weight. Cellulose can be found in the stem, the leaves or the seeds of plants. During the last decade there has been a renewed interest in the natural fibre as a substitute for glass, motivated by potential advantages of weight saving, lower raw material price, and 'thermal recycling' or the ecological advantages of using resources which are renewable. Natural fibres, however, have their shortcomings, and these have to be solved in order to be competitive with glass or other matrices such as epoxies, polyester, etc. Even though natural fibres have lower durability and lower strength than glass fibres, their properties can be improved tremendously through pretreatment of fibre.

INTROP: Highlight

BAST FIBRES

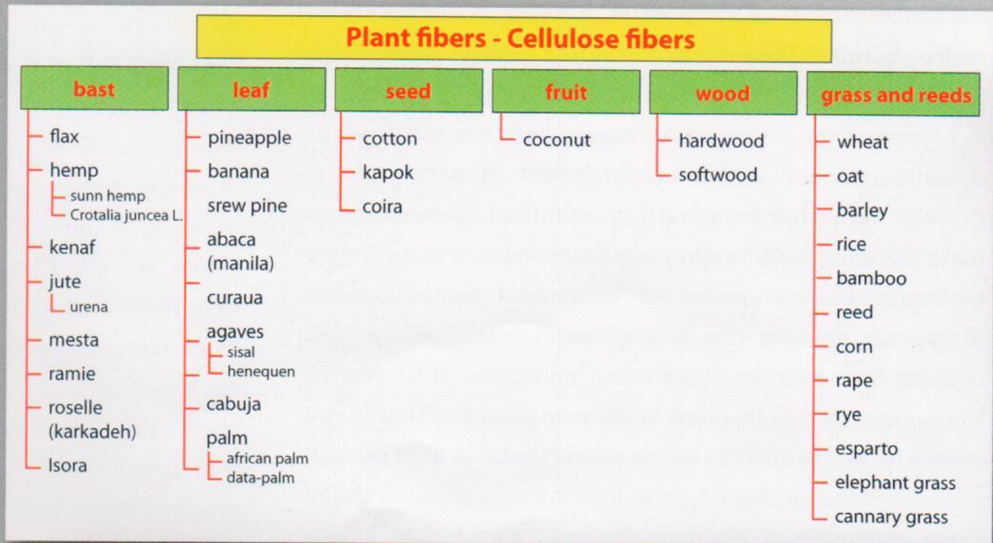
In general, the bast consists of a wood core surrounded by a stem. Within the stem there are a number of fibre bundles, each containing individual fibre cells or filaments. The filaments are made of cellulose and hemicellulose, bonded together by a matrix, which can be lignin or pectin. The pectin surrounds the bundle thus holding them on to the stem. The pectin is removed during the retting process. This enables separation of the bundles from the rest of the stem. Some examples of plants of this nature include kenaf, flax, hemp, jute and ramie.

During the processing of a biocomposite, the fibre bundles are normally sprayed/impregnated with a synthetic resin prior to being compressed at certain conditions. The strength of the resulting biocomposites depends very much on the cleanliness of the individual fibre for instance, in the case of flax, a much stronger composite is obtained if the fibre bundles are pre-treated with alkali to remove the lignin between the cells.

THE USE OF NATURAL FIBRES IN BIOCOMPOSITE INDUSTRY

The use of natural fibres for technical composite applications has been the subject of intensive research in both Europe and USA. Many automotive components are already produced in natural composites, mainly based on polyester or PP and fibres like flax, hemp or sisal. The adoption of natural fibre composites in this industry is lead by motives of : 1.) price 2.) weight reduction and 3.) marketing ('processing renewable resources') rather than technical demands. The range of products is restricted to interior and non-structural components like door upholstery or rear shelves.

There are many new product potentials to be considered for future development. Markets for existing products will expand but whole new markets are possible. Some of the applications of natural fibres include geotextiles, filters, sorbents, structural composites, non-structural composites, molded products, packaging, and combinations with other resources. Geotextiles are made using long bast or leaf fibers from such plants as kenaf, jute, cotton, sisal, agave, etc. which can be formed into flexible fiber mats via either physical entanglement (carding), nonwoven needling, or thermoplastic fiber melt matrix technologies. In carding, the fibers are combed, mixed and physically entangled into a felted mat. These are usually of high density but can be made at almost any density. A needle punched mat is produced in a machine which passes a randomly formed machine made web through a needle board that produces a mat in which the fibers are mechanically entangled. The density of this type of mat can be controlled by the amount of fiber going through the needle board or by overlapping needled mats to give the desired density. In the thermoplastic fiber matrix, the natural fibers are held in the mat using a thermally soften thermoplastic fiber such as polypropylene or polyethylene. Medium- to high-density fiber mats can be used in several ways and one of if is as Geotextiles. Geotextiles have a large variety of uses such as mulching mat for newly planted seedlings. The mats provide the benefits of natural mulch; in addition, controlled-release fertilizers, repellents, insecticides, and herbicides can be added to the mats as needed.



Sources of cellulose fibres from various parts of plants (Kozlowski, 2006)

Table 1. World Inventory of Biomass

Fiber Source	World (dry metric tons)
Wood	1,750,000,000
Straws	1,145,000,000
Stalks	970,000,000
Sugar cane	75,000,000
Reeds	30,000,000
Bamboo	30,000,000
Cotton staple	15,000,000
Core (jute, kenaf, Hemp)	8,000,000
Papyrus	5,000,000
Bast (jute, kenaf, hemp)	2,900,000
Cotton linters	1,000,000
Esparto grass	500,000
Leaf (sisal, abaca, henequen)	480,000
Sabai grass	200,000
TOTAL	**4,033,080,000**

Source: Rowell, 2006

Some advantages and disadvantages of natural fibres

ADVANTAGES	DISADVANTAGES
Low specific weight than glass	Lower strength properties particularly its impact strength
Higher specific strength and stiffness - benefit especially in parts designed for bending stiffness	High moisture absorption
Renewable resource - production requires little energy, CO2 is used while oxygen is given back to the environment.	Low durability
Producible with low investment at low cost	Variable quality
No wear of tooling, no skin irritation	Poor fire resistance
Thermal recycling is possible	Price can fluctuate

Properties of natural fibres in comparison with glass fibres

Properties	Fibre Type									
	E-glass	Kenaf	flax	hemp	jute	ramie	coir	sisal	abaca	cotton
Density g/cm3	2.55	1.5	1.4	1.48	1.46	1.5	1.25	1.33	1.5	1.51
Tensile strength* 10E6 N/m2	2400	350-600	800 - 1500	550 - 900	400 - 800	500	220	600- 700	980	400
E-modulus (GPa)	73	40	60 - 80	70	10 - 30	44	6	38	-	12
Specific (E/density)	29	27	26 - 46	47	7 - 21	29	5	29	-	8
Elongation at failure (%)	3	2.5-3.5	1.2 - 1.6	1.6	1.8	2	15 - 25	2 - 3	-	3 - 10
Moisture absorption (%)	-	-	7	8	12	12 -17	10	11	-	8 - 25
price/Kg ($), raw (mat/fabric)	1.3 (1.7/3.8)	0.33-0.88	- 1.5 (2/4)	0.6 - 1.8 (2/4)	0.35 1.5/0.9 - 2	1.5 - 2.5	0.25 -0.5	0.6 - 0.7	1.5 - 2.5	1.5 - 2.2

** tensile strength strongly depends on type of fibre, being a bundle or a single filament (Source: Kozlowski, 2006)*