COMPOBASTFIBER

GUIDE

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LEARN

“For a DESIGNER to continually learn about materials is not extracurricular. It's absolutely essential."

A designers guide to exploring Bio-Composites

The comprehensive Compobast Fibres guide is here for all sustainable designers who are in search of information and guidance through the world of old-new materials. We would like to bring you a resource you can glide through with ease and comfort, finding all the information needed for your environmental and sustainable practices and design criteria. This guide aims to introduce product and fashion designers to the idea of “the composite” as a structural, shapable material, useful for producing both flat and organic forms, and to suggest possibilities for replacing conventional fibers with natural fibers and biopolymers. Our experiments are by no means comprehensive, as material science in this area is relatively new and samples of the polymers expensive and challenging to use in our conventional workshop setting. Having said that, we feel it is important for designers to jump on board and start experimenting in this area, and join in the conversation about bio-composites and bio-plastics. Designers’ formgiving knowledge, plus a willingness to conduct creative hands-on trials, is a valuable contribution to the field. It can support and even direct material scientists toward developing the most useful materials.

DESIGNERS responsibility

DESIGN FOR THE BETTER

Sustainability - How can we as designers encourage and support the necessary movement towards a more sustainable society? The nowadays society has to be seen as a comunity of many individuals and their consequential behavior. Their decisions matter, because they have major influence in the production of the companies. In fact, to sustain for future generations, we will have to change the current consumption based system.

But do we really just want to sustain, should we not also want to enjoy a certain lifestyle and not give up everything for merely surviving? There must be a common way how the consumer can do good while still shopping. Following, are the ideas of the new Lifestyle groups like LOHAS (Lifestyle of Health and Sustainability) and LOVOS (Lifestyle of Voluntary Simplicity) which want to combine a good lifestyle with healthy and good products. They support new values and a new consciousness which creates special needs to live a rather stress free, slower and healthier lifestyle, for a sustainable yet joyful live. LOAHS flollowers want to use their income for good products in the sense that they serve their own needs, but also do good to the environment and to society.

The creation of new designs and products must include the aspect of working towards less harmful substitutes for already existing products and not only the creation of new and fancy eco-products for the well-to-do minority. Future design is about innovation, in the point of view of quality and long lasting products as well as efficiency to use less energy and resources.

Starting from the products' point of view, every single product has its own life story. First it is gained through raw material extraction from our planet, then moulded into its shape, transported to a retailer in some other part of the world, bought by a customer, used, to then end up in a landfill. Every step in this production chain has an impact on our environment and on society. Of course, it is the companies producing and selling products who are responsible of the process, but in the end, it is the consumer who demands the products. Therefore, we as designers have the responsibility to work as agents for a sustainable change, and to provide the consumer with qualitative and sustainable options to fullfill their needs.

NO DOUBT, NOWADAYS WE CONSUME WAY TOO MUCH, BUT YOU CAN NOT DENY IT. INSTEAD, LETS CHANGE WHAT WE CONSUME.

frauke godat

01 chapter

materials

WHAT IS a composite?

MAN-MADE COMPOSITE = BIOMIMICRY

Plants are natural composites whose structures are composed of flexible fibers held upright (as stems) by various natural polymers such as cellulose, lignin, and pectin.

A tree, for example, is a natural composite made from uni-directionally oriented chains of reinforcement fibers set into a lignin polymer. Simply put, the fibers in the main trunk are oriented vertically and held in place with a lignin "glue" to counteract forces (such as wind) that might snap the trunk. Where the trunk branches are, fibers are oriented horizontally in the direction necessary to counter forces acting on the branches (such as gravity). This natural composite structure is what gives wood tensile strength and makes it a popular building material *(plate 1)*. Steaming wood fibers at high temperatures softens its natural lignin polymer, allowing the wood to be formed into a shape which it will retain after cooling. Thonet perfected this steam bending process in the 1890s *(plate 2)*.

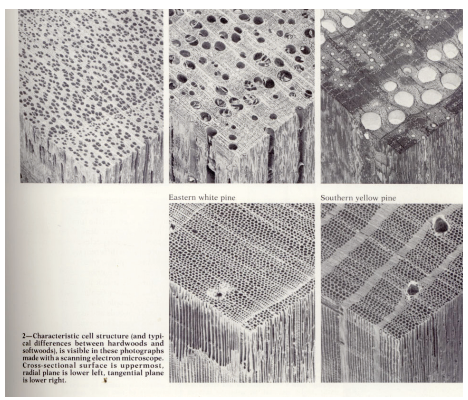


plate 1:
Woods under the microscope from Bruce Hoadleys Understanding Wood

Man-made composites date back to ancient Egypt, where straw was mixed with clay to make stronger wall structures. Clay on its own is very brittle, as are most polymers. Straw fibers have high tensile strength and flexibility, but can not be utilized on their own. They need a binder to hold them as a group, oriented in a certain direction, and to be stiffened. For centuries we have been "stealing" fibers from the plant for our own engineered materials (sometimes separating the fibers from their natural polymer), reusing them in combination with our own chosen polymer. During the last century, we have developed synthetic fibers and polymers for use in composites. We use these composites to create new materials in the shapes we desire (flat sheets, cast forms, organically shaped shells).

plate 2:
Thonet 214 chairs

FIBERS

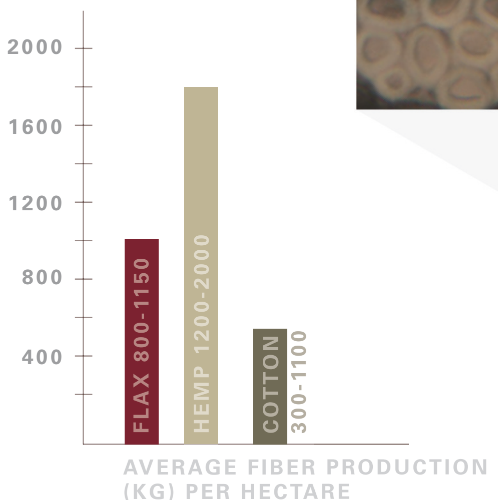
Fibers are hair-like materials that tend to stick to each other. They can be twisted together to form filaments or teased into mats. Filaments can be twisted into yarn, thread, or rope. These can be woven to create textiles with tensile strength in two directions or knitted to create elastic textiles. Mats are made using randomly-oriented shorter fibers. These can be needle-punched to create felted textiles. Each technique presents different structural possibilities for designing with fiber. When combined with polymers to form a composite, the orientation and structure of the fibers is to be chosen in order to counter the structural stresses inherent in the object designed.

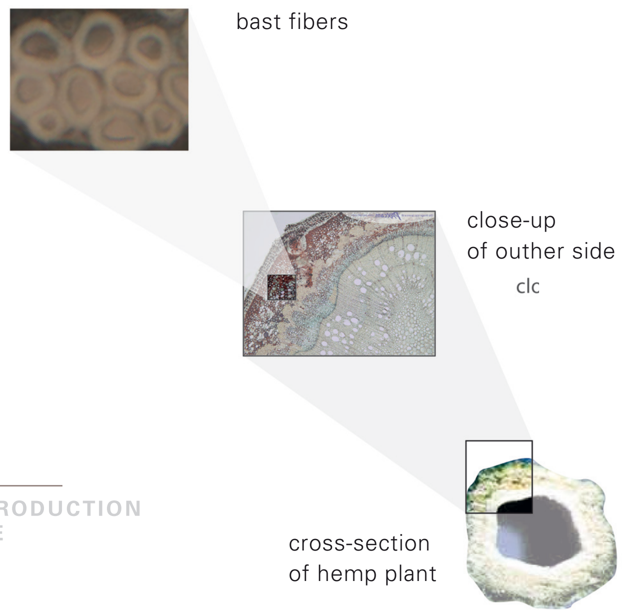
Currently, man-made fibers such as glass fiber and carbon fiber dominate as composite reinforcements, but natural fibers can be used in addition or in substitution for these man-made fibers. Potential natural fibers include bast fibers, seed fibers (for example, cotton), bamboo fibers, and leaf fibers (such as sisal). The most commonly harvested bast fibers for use in man-made composites are flax (linen), hemp, ramie (nettle), kenaf, and jute. This study will explore structural, ethical, and creative possibilities and limitations for using natural and bast fibers in the design of composite household products and fashion.

Bast fiber plants, the same as a tree, contain cellulose fibers that are oriented to hold the stem upright. The inner bark (just underneath the skin) is the location of food-conducting tissues in the plant, or phloem, and contains the fibers known as bast fibers. Like wood, they are both strong and flexible, and also useful for man-made composites. In nature, the fibers are held upright using lignin and pectin. To make use of the fibers, they must first be separated from the xylem (a brittle, woody inner core) by softening the natural polymers in the plant (in bast plants these are lignin and pectin). This process is called retting. Water is the traditional method of softening the core, but chemicals or enzymes can also be used.

The bast fibers are separated from the woody core using rollers (breakers). The clumps are then cleaned and broken up then combed in a process called carding. Fibers are then processed in one of several ways. They can be twisted together and spun (to make thread for weaving or knitting), matted (for non-woven mats or needle-punched uses), or pulped (for paper making).

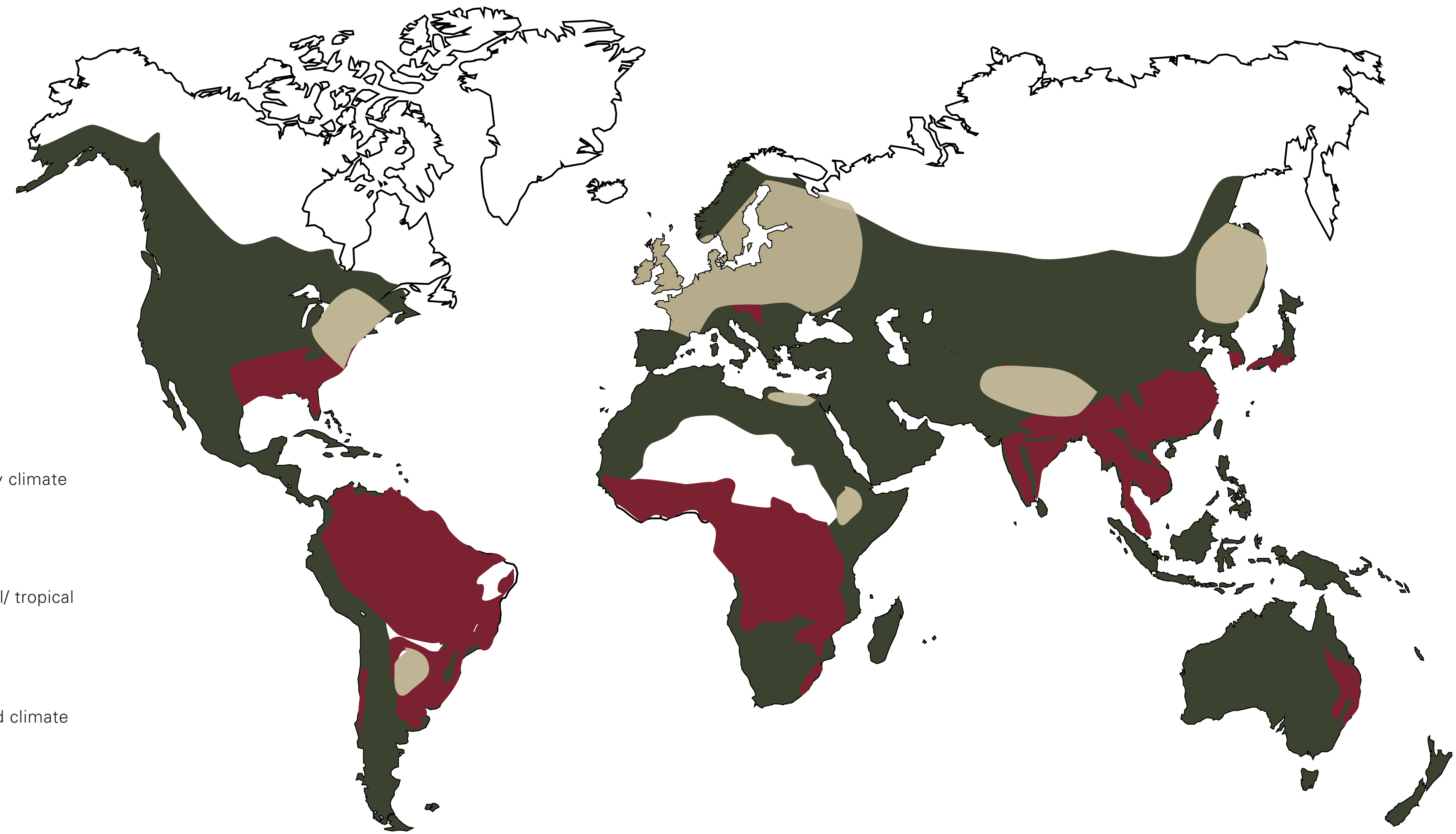
This study will explore structural, ethical, and creative possibilities and limitations for using natural and bast fibers in the design of composite household products and fashion.





ADVANTAGES OF BAST FIBERS IN COMPOSITES	DISADVANTAGES OF BAST FIBERS IN COMPOSITES
Biodegradable	Might biodegrade prematurely, weakening composite
Renewable resource	Look of natural fiber composite is not aesthetically pleasing to some people.
Can use waste fibers	Skin might be necessary to conceal natural fibers.
Tensile strength is comparable to synthetics	Less tested methods for using in composities.
Some bast plants use fewer pesticides and less water than conventional natural fibers like cotton.	Overall resources consumed may be less over the entire life cycle in some synthetics(when compared through MIPS calculations - note: they do not take into account toxicity or type of land use).
Some bast plants can be grown on land that is unusable for farming.	Longevity in composites not yet comprehensively tested.

CULTIVATION/ climate



Hemp
almost any climate

Cotton
subtropical/ tropical

Flax
cool humid climate

	LINEN	HEMP	COTTON	SOFT WOOD	FIBER GLASS	CARBON FIBER	ARAMID (KEVLAR)	PET
TYPE	natural	natural	natural	natural	inorganic	inorganic	inorganic	inorganic
SOURCE	Flax Plant	Cannabis genus plant	Cotton Plant	Coniferous Trees	Sand	Carbonized rayon or acrylic	Para-Aramid synthetic fiber	thermoplastic polymer resin
CLIMATE REQUIRED	Flax grows best at northern temperate latitudes, in cool, humid climates and within moist, well-plowed soil.	Hemp can grow in most climates except subarctic. Its is restricted by law in some areas.	Cotton is primarily grown in dry tropical and subtropical climates in the Northern and Southern hemispheres at temperatures between 11°C and 25°C. Plenty of sunshine, and a moderate rainfall.	Coniferous trees, as pine, fir, hemlock, and spruce, grow in the boreal forests of the Northern hemisphere and in similar cool climates further south.				
KEY BENEFICIAL ATTRIBUTES	Low cost as by-product of Linseed production, commercially available in large quantities. Exceptional coolness in hot weather. Exceeds cotton in coolness, luster, strength, and length of fiber.	Fiber strength and durability (particularly resistance to decay). Low footprint on soil, low water usage, little to no pesticides needed. Fairly easy to grow, reaches maturity fast.	Used in the production of a large number of textile products. Cotton fabrics are natural, breathable and comfortable. Fiber fineness: easy dyeing of the yarn.	Strong, durable, light in weight, and easy to work. Offers natural beauty and warmth to sight and touch. Properties varry with particular trees.	Strong. Semi transparent.	Extremely high strenght.	High tensile strength per low weight, chemical and cut resistance. Low electrical conductivity, thermal shrinkage; excellent dimensional stability; flame resistant, self-extinguishing.	Good antiosmosis, low water absorbance. Easy to recycle. Wear and corrosion resisting with high strength and smooth finish. Crystal clear, safe, lightweight, design flexibile, long shelf-life.

	LINEN	HEMP	COTTON	SOFT WOOD	FIBER GLASS	CARBON FIBER	ARAMID (KEVLAR)	PET
KEY BARRIER ATTRIBUTES	Low yields per acre. Limited rotations, generally three years. Lower tensile strength of the oil-seed variety, as compared to other bast plants, such as hemp. Toxic chemicals used in retting, wrinkles very easily.	The development of hemp as a new legal crop in North America must be considered in relation to illicit cultivation.	Cotton plants are vulnerable to many pests, requiring the use of pesticides. Cultivation uses large amounts of chemical as Hexachlorobenzene, Aldrin, Dieldrin, DDT and DDT. High water usage during irrigation.	Wood defects affect its grading, appearance, use, and possibly its strength. Some are natural wood characteristics: knots, shakes, and pitch pockets, and effects of manufacturing: checks and warping.	Brittle.	Brittle. A lot of energy is used during manufacturing process.	Sensitive to the ultraviolet component of sunlight which degrades and decomposes Kevlar. Requires protection if used outdoors.	Undergoes a variable change in dimensions, a shrinkage and expansion effect to the structure, when exposed to heat.
FIBER DENSITY (G /CM3)	1,5 g/cm3	1.48 g/cm3	1.54-1.56 g/cm3	Pine - 0.5 g/cm3	1,7 - 2,7 g/cm3	1,79 g/cm3	Kevlar 29: 1.44 g/cm3, Kevlar 49: 1.44 g/cm3, Kevlar 149: 1.47 g/cm3	1.4 g/cm3 (20 °C), amorphous: 1.370 g/cm3, crystalline: 1.455 g/cm3
YOUNG'S MODULUS (GPA)	34 GPa	89 GPa	23,4 - 86,8 GPa	Douglas Fir - 13 GPa	23.4 - 86.9 GPa	230-240 GPa	170 - 190 GPa	2-2.7 GPa
ELONGATION (%)	2,75%	3,5%	5,5%		4,7 - 7,7%	1.65% - 23%		50–150%
TENACITY (MNTEX -1)	5,5 grams-force per denier	4,5 grams-force per denier	3,5 grams-force per denier					

	LINEN	HEMP	COTTON	SOFT WOOD	FIBER GLASS	CARBON FIBER	ARAMID (KEVLAR)	PET
COST	Fiber Flax $2,000 - $4,000/ton	$1.88/kg in 1995. Hemp price heavily relies on local processing and buying conditions.	'A' Index 147.55 (0.80) USD				A gram of kevlar thread will cost about 50 cents to a dollar	1,050-1,100/ tonne FD (free delivered)
FERTILIZER	For high quality fiber Flax common farming fertilizers might be used.	Growing hemp may require addition of up to 110 kg/ha of nitrogen, and 40–90 kg/ha of potash. Hemp particularly requires good nitrogen fertilization.	one-third of a pound of chemical fertilizers and pesticides for every pound of cotton harvested.	Fertilization is not required unless the soil lacks nutrients, which can be determined through testing. Usually, trees growing in urban and suburban environments require fertilization.				
TOXICITY OF PROCESSING	chemicals used in retting	No toxicity has been demonstrated at processing point.	Fertilizers and pestides used for harvesting Cotton are highly toxic.	Depends on the product wood is destined for. Toxicity is primarily related with the resins and glues used in production.	Research shows that the composition of this material (asbestos and fiberglass are both silicate fibers) causes similar toxicity as asbestos.	Potential health effects of these particles are uncertain.	Industrial eperience shows the inhalation of Kevlar fibrous dust and fly may cause mechanical irritation of the mucous membrans of nose and throat.	High levels of Benzene exposure in factory workers have been linked to cancer.

FLAX/ linseed

Flax is one of the oldest fibre crops in the world. Already 30,000 years ago there where wild fibre flax plants found in Dzudzuana, Georgia, indicating already being used for ropes that where spun and dyed with natural pigments.[1] Flax was used by the ancient Egyptians, Romans, Greeks and Hebrews as food, clothing and medicine.
Nowadays, in North America mostly, Linseed is grown for its seed production. Textile flax is primarily grown in Canada, China and Europe including mostly France, Belgium, Netherlands, Spain, but also Russia and Egypt are producers of flax for commercial textile.[2]

Production:
Flax Plant - Linum usitatissimum, grows annually up to 120 cm, flowering in the color blue. Its fruit is a round, dry capsule 5–9 mm diameter, containing several small brown seeds, 4–7 mm long. Flax belongs to the group of Bast-fibres, which means their fibres are "collected from the inner bark, or bast, of the stem."[3] Flax grows in 12 stages, and its life cycle consists of a 45 to 60 days vegetative period, 15 to 25 days flowering period, and a maturation period of 30 to 40 days. Best climate to grow flax is in the northern latitudes, where it is cool and wet. The soil should be moist and ploughed. World wide two types of flax are used for industrial production: Fibre Flax and (Lin)Seed Flax.

"Flax grown for seed is allowed to mature until the seed capsules are yellow and just starting to split; it is then harvested and dried to extract the seed."[4]

"Fibre Flax uses different harvesting methods mechanical but also includes manual work for high quality and long fibres, which increases the price enormous." To get the best and longest fibres, the flax needs to be pulled out and not cut. After harvesting it will be left on the fields to dry and then remove the seeds. "Then flax is exposed to moisture to break down the pectin that binds the fibres together."[5] Next step is the retting, which has the highest environmental impact throughout the production process. "The preferred method is to spread out in the fields and exposed to

rain, dew and sunshine for several weeks. After that the fibres are separated from the straw (shives), and then graded into the short fibres (tow) which is used for coarser yarns, or the longer fibres (line) which will be used to create the finest linen yarn."[6] The Flax fibres' length can be up to 90 cm, and average 12 to 16 microns in diameter. The fibres are already much longer than for example cotton (about 3.5 cm) but shorter than Hemp which measures from 90 cm to 460 cm.

Common Use & Feeling
Linen is a fabric made from flax fibres, most commonly used in high-quality products because through the process of production it becomes an expensive fibre/material. It is very well known for its cool- and lightness feeling for summer clothes.

The shorter flax fibers may also be used in high-quality sheets and kitchen wear. It is also a valued material for premium quality artist canvas. "Linen is preferred to cotton for its strength, durability and archival integrity. For industry, it serves as a pigment binder for oil paint and a drying agent for paints, lacquers and inks. It is sometimes used as a wood finish, in varnishes, printing inks, and soaps, and can be combined with cork to make linoleum."[7] Flax is also considered an environmentally orientated alternative to synthetics fibres in fibre-reinforced bio-composites.[8]

Disadvantages

Commonly grown, the farming uses agricultural chemicals, fertilizers, and pesticides which keep weeds under control. It can grow also without the use of fertilizers as long as there is enough water available. For growing high quality fibres there is a need for moist, but mild climate. Flax also has a relatively low yield per acre, which increases its price. There is also the issue of field rotations about every three years. The tensile strength of the oil-seed flax is way lower, if compared to other bast plants, such as hemp.

Main problem concerning the environmental impact is the retting, which implies the process when the fibres get separated from the stalk. Commonly used methods work with open retting ponds, retting on the field or earlier; running-water from a river. Small bundles of stalks are let to rot, to then easily separate the fibres from the woody parts. This process causes a huge amount of waste water, which needs to be dealt with.

Advantages

Water usage for growing flax is not very high, which prohibits high environmental impact on water consumption. As positive aspects, it should be mentioned that linen (also bast fibres as hemp, jute and kenaf) can be grown on fields unsuitable for food production, regarding to e.g. contamination with heavy metals, because the fibre-plants tend to clean the soil.

Linseed flax would be a very efficient plant, because nearly all the parts are valuable for further production. The main product are the seeds, which will be further processed. They can be used for cooking, cracked or whole, or ground into flour. Another major use is the production of oil, which is supposed to be very healthy because it contains high amount of "essential omega-3 fatty acids; the oil is believed to provide benefits to arthritis and lupus patients by reducing inflammation."[9] After pressing the oil, the seeds make a good feed for e.g. chickens and other livestock. They serve them with a lot of protein and dietary fibre.
The flax straw in this case, is a by product, which makes it a very cheap material. At the current stage, most commonly the straw is removed from the field and handled as waste, burnt on the fields. Either way, a waste of resources and increase of landfill waste or CO2- rise.

1Tiina Härkäsalmi, Environmentally conscious design research of linseed fibres

2 http://oecotextiles.wordpress.com/2010/06/30/linen/

3 http://oecotextiles.wordpress.com/2010/06/30/linen/

4 http://en.wikipedia.org/wiki/Flax

5 http://www.libeco.com/en/about-linen/from-flax-to-linen.aspx

6 http://www.libeco.com/en/about-linen/from-flax-to-linen.aspx

7 http://oecotextiles.wordpress.com/2010/06/30/linen/

8Tiina Härkäsalmi, Environmentally conscious design research of linseed fibres

9 http://oecotextiles.wordpress.com/2010/06/30/linen/

Benoit Millot

fibers

HISTORY

Hemp is one of mankind's oldest cultivated crops. Along with wheat, beans, and rice, early Neolithic farmer communities along the Wei and Yellow Rivers in China produced Hemp. It was first utilized and domesticated in ancient Taiwan and China. 10,000-4000 B.C. Through long-term efforts, the ancient Chinese domesticated hemp from a wild plant into a cultivated crop approximately 8000 B.C.

The weaving of hemp fiber as industry began 10,000 years ago, at approximately the same time as pottery making and prior to metal working. Hemp was used for clothing in China, dating back in the third century B.C. during the reign of The Yellow Emperor, Huang-Ti. – "Columbia History of the World", Harper & Row, 1981. [10]

Interesting historical facts about hemp:

* In 1941 Henry Ford built a car using materials such as plastic made from hemp and wheat straw.
* George Washington and Thomas Jefferson owned hemp plantations. The colonial government mandated people to grow hemp. Settlers utilized hemp fiber not only as money, but paid their taxes as well.
* The original Levi Strauss jean was made of hemp.
*The United States Declaration of Independence, July 4, 1776, was written on hemp paper.[11]

PRODUCTION

Hemp can be cultivated in most climate zones, except the Sub Arctic and Tropical Wet-Dry. Hemp is a fast growing crop and the land requirements are low. More so, it also absorbs heavy-metal contamination from the air and the soil, improving water quality in the area where it is grown. It is therefore used as a rotation crop because of its "soil healing" properties, in contrast to cotton for example, which degrades the soil properties. Hemp produces more fiber than cotton and flax when grown on the same land.

PESTICIDE FREE

In general, hemp is resistant to pests. Even though there are pests that can attack hemp, this can be avoided without use of chemicals.

France, England, Germany and the Netherlands have all commercially cultivated hemp without the use of pesticides. Eastern European and Chinese hemp fabrics have been shown to be free of harmful substances, in accordance with standards established by the Natural Textile Association (Arbeitskreis Naturtextilien) - http://www.green.net.au/gf/hemp_cultivation.htm.

Hemp fibers are famous because of their ultimate strength. They are widely used by US Army for producing ropes and parachutes. Interestingly enough, the US Army preferrs imported fibers that are water retted to ground retted domestic ones. An added value of hemp is its oilseed, used in the food industry.

PRODUCTION PROCESS

Hemp fiber is usually ready to harvest in 70-90 days after planting. A special machine with rows of independent teeth and a chopper is used for harvesting hemp for textile use.

Once the crop is cut, the stalks are allowed to rett (removal of the pectin [binder] by natural exposure to the environment) in the field for four to six weeks - depending on the weather - to loosen the fibers. While the stalks lay in the field, most of the nutrients extracted by the plant are returned to the soil as the leaves decompose. The stalks are turned several times using a special machine for even retting and then baled with existing hay harvesting equipment. Bales are stored in dry places, including sheds, barns, or other covered storage. The moisture content of hemp stalks should not exceed 15%. When planted for fiber, yields range from 2-6 short tons (1.8-5.4t) of dry stalks per acre, or from 3-5 short tons (2.7-4.5 t) of baled hemp stalks per acre in Canada.[13]

sources

10 http://www.ushemp-museum.com/Ancient-China.html

11 http://oecotextiles.wordpress.com/2010/06/02/characteristics-of-hemp/

12 http://www.made-how.com/Volume-6/Industrial-Hemp.html

13 http://en.wikipedia.org/wiki/Legality_of_cannabis

http://www.innvista.com/health/foods/hemp/croppest.htm

http://norml.org/index.cfm?Group_ID=3395

GRAIN PROCESSING

Hemp seeds must be properly cleaned and dried before storing. Extraction of oil usually takes place using a mechanical expeller press under nitrogen atmosphere, otherwise known as mechanical cold pressing. Protection from oxygen, light, and heat is critical for producing tasty oil with an acceptable shelf life. Solvent extraction methods are also emerging for removing oil since they achieve higher yields. Such methods use hexane, liquid carbon dioxide, or ethanol as the solvent. Refining and deodorizing steps may be required for cosmetics manufacturers. A dehulling step, which removes the crunchy skin from the seed using a crushing machine, may be required. Modifications to existing equipment may be required to adequately clean the seeds of hull residues.

FIBER PROCESSING

To separate the woody core from the bast fiber, a sequence of rollers (breakers) or a hammer mill are used. The bast fiber is then cleaned and carded to the desired core content and finesse, sometimes followed by cutting to size and baling. After cleaning and carding, secondary steps are often required. These include matting for the production of non-woven mats and fleeces, pulping (the breakdown of fiber bundles by chemical and physical methods to produce fibers for paper making), and steam explosion, a chemical removal of the natural binders to produce a weavable fiber. Complete processing lines for fiber hemp have outputs ranging from 2-8 short tons/hour (1.8-7.2 t/hr). [12]

MAJOR USES OF INDUSTRIAL HEMP FIBERS:

Paper production
Textiles
Moulded plastics
Construction
Livestock bedding

USES FOR THE OTHER PARTS OF HEMP PLANT:

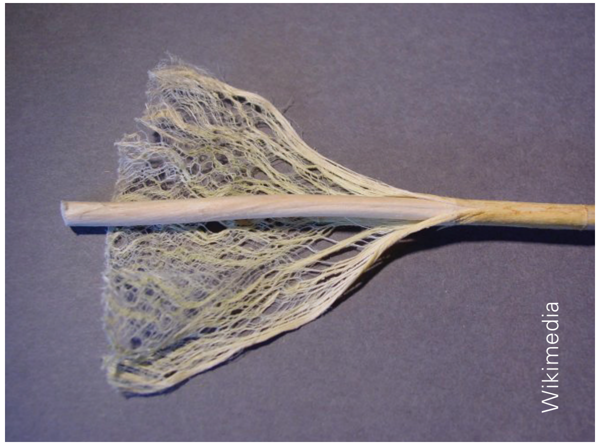
Food
Medicines
Essential oils
Nutritional supplements
Livestock feed

STANDARDS

In many countries, the cultivation of hemp is forbidden by legislation, this is because of THC - delta-9 tetrahydrocannabinol that is commonly used as a drug. This prohibition was established at the beginning of the 20th century. Today, in Europe and Canada, cultivation of hemp is allowed for research and commercial purposes if its THC level does not exceed 0,3%.

In the United States, some states (e.g. Hawaii, Kentucky or Montana), approved a law to allow for the cultivation of hemp, "HOUSE BILL 1250 -Industrial Hemp - Pilot Program." The regulation uses the same 0,3% THC level to define industrial (legal) hemp. Farmers require a license for cultivation, according to guidelines of the bill. There are ongoing works on hemp cultivation legislation (regarding its legalization) in other States as well.

Industrial hemp, however, is characterized by having low levels of THC (delta-9 tetrahydrocannabinol) and high in CBD (cannabidiol), approximately 1%.


Wikimedia


Anja-Lisa

CARBON/ fibers

Carbon fiber is an extremely strong, durable and very lightweight material produced in a process of carbonization of organic fibers. Also called graphite fiber, the term is used to describe fibers that have carbon in excess of 99%, whereas carbon describes fibers with 90% carbon or more.

APPLICATIONS

Carbon fiber is broadly used in composites since it is very light, extremely strong and durable. Because of its high cost and low availability, carbon fiber is mainly used in specialized technology including aerospace and nuclear engineering, transportation, and sports equipment manufacturing. It has chemical resistivity and non-corrosive properties. Carbon fiber is thermal conductive and is unusually flame retardant. Electric conductivity properties of carbon provide new uses in electronics technology.

Larry C. Wadsworth created following list regarding application of carbon divided by the major properties:

1. Physical strength, specific toughness, light weight aerospace, road and marine transport, sporting goods
2. High dimensional stability, low coefficient of thermal expansion, and low abrasion missiles, aircraft brakes, aerospace antenna and support structure, large telescopes, optical benches, waveguides for stable high-frequency (GHz) precision measurement frames
3. Good vibration damping, strength, and toughness audio equipment, loudspeakers for Hi-fi equipment, pickup arms, robot arms
4. Electrical conductivity automobile hoods, novel tooling, casings and bases for electronic equipments, EMI and RF shielding, brushes

5. Biological inertness and x-ray permeability medical applications in prostheses, surgery and x-ray equipment, implants, tendon/ligament repair
6. Fatigue resistance, self-lubrication, high damping textile machinery, genera engineering
7. Chemical inertness, high corrosion resistance chemical industry; nuclear field; valves, seals, and pump components in process plants
8. Electromagnetic properties: large generator retaining rings, radiological equipment [14]

HISTORY

„The existence of carbon fiber came into being in 1879 when Thomas Edison recorded the use of carbon fiber as a filament element in an electric lamp.

In the 1960s, it was realized that carbon fiber is very useful as reinforcement material in many applications. Since then, researchers in the USA, the UK and Japan have greatly improved the process. In the 1960s, high-strength PAN-based carbon fiber was first produced in Japan and the UK, and pitch-based carbon fiber was first produced in Japan and the USA."[15]

PRODUCTION

Carbon fibers are manufactured by controlled pyrolysis, a process of organic precursors in fibrous form. Basically the process of making carbon fibers consists of many stages of heating at different temperatures and atmospheres, depending on the step during the process and the type of the material a precursor is used. It consists of a heat treatment that removes the oxygen, nitrogen, and hydrogen from the precursor and changes into almost pure carbon.
Two most commonly used precursors for production of Carbon Fibers are PAN and Pitch.

PAN - Polyacrylonitrile-based carbon fiber is more expensive to produce but offers higher tensile strenght. Polyacrylonitrile is a vinyl polymer.

Pitch-based carbon fibers are produced from coal tar and petroleum products.

Other procursors used in production of carbon fibers are: Cellulosic fibers (viscose rayon, cotton), Mesophase pitch-based carbon fibers, Isotropic pitch-based carbon fibers and Gas-phase-grown carbon fibers and certain phenolic fibers.

"Mesophase pitch fibers, offer designers a different profile. They are easily customized to meet specific applications. They often have a higher modulus, or stiffness, than conventional PAN fibers, are intrinsically more pure electrochemically, and have higher ionic intercalation. Mesophase Pitch fibers also possess higher thermal and electrical conductivity, and different friction properties."[16]

There are many methods for producing carbon fibers, but all of them uses huge amount of energy. Heating temperature during production process of carbon fibers varies from 1000°C to above 2000°C. Manufacturing of higher strength carbon fibers uses higher temperature.

Carbon fiber production processes for different precursors:

PAN PROCESS:

Oxidative stabilization: the polyacrylonitrile precursor is first stretched and simultaneously oxidized in a temperature range of 200-300°C. This treatment converts thermoplastic PAN to a non-plastic cyclic or ladder compound.

Carbonization: after oxidation, the fibers are carbonized at about 1000°C without tension in an inert atmosphere (normally nitrogen) for a few hours. During this process, the non-carbon elements are removed as volatiles, to give carbon fibers a yield of about 50% of the mass of the original PAN.

Graphitization: depending on the type of fiber required, the fibers are treated at temperatures between 1500-3000°C, which improves the ordering, and orientation of the crystallites in the direction of the fiber axis.

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PITCH PROCESS:

Pitch preparation: it is an adjustment in the molecular weight, viscosity, and crystal orientation for spinning and further heating.

Spinning and drawing: in this stage, pitch is converted into filaments, with some alignment in the crystallites to achieve the directional characteristics.

Stabilization: in this step, some kind of thermosetting is done to maintain the filament shape during pyrolysis. The stabilization temperature is between 250 and 400 °C.

Carbonization: the carbonization temperature is between 1000-1500°C.

RAYON PROCESS:

Stabilization: stabilization is an oxidative process that occurs through steps. In the first step, between 25-150°C, there is physical desorption of water. The next step is a dehydration of the cellulosic unit between 150-240°C. Finally, thermal cleavage of the cyclosidic linkage and scission of ether bonds and some C-C bonds via free radical reaction (240-400° C) and, thereafter, aromatization takes place.

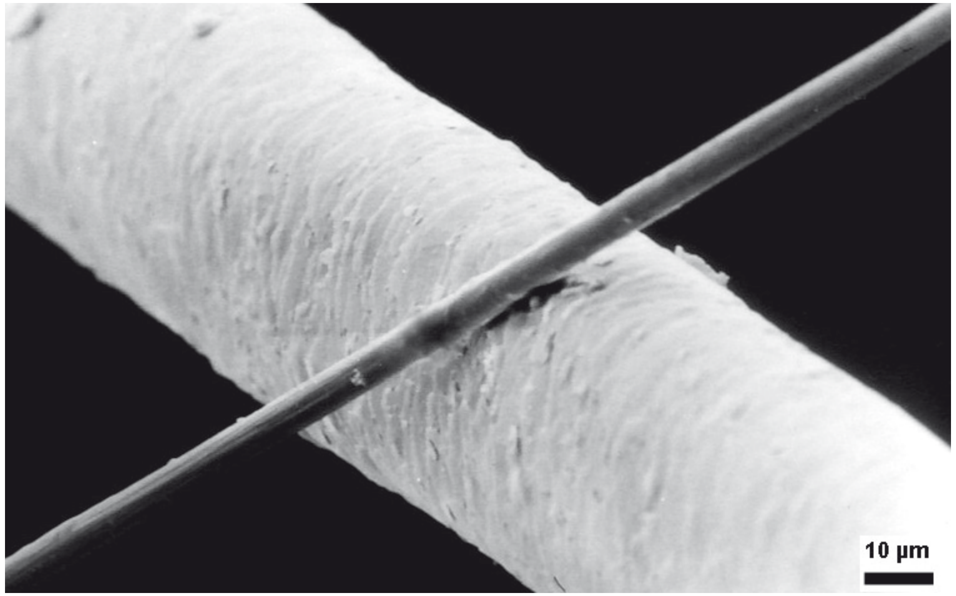
Carbonization: between 400 and 700°C, the carbonaceous residue is converted into a graphite-like layer.

Graphitization: graphitization is carried out under strain at 700-2700°C to obtain high modulus fiber through longitudinal

orientation of the planes.

HIGH QUALITY CARBON FIBER PRODUCTION:

„It is well established in carbon fiber literature that the mechanical properties of the carbon fibers are improved by increasing the crystallization and orientation, and by reducing defects in the fiber. The best way to achieve this is to start with a highly oriented precursor and then maintain the initial high orientation during the process of stabilization and carbonization through tension." [17]



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GLASS/ fibers

FIBERGLASS

Fiberglass is a silica-based material consisting of extremely fine fibers of glass.

Fiberglass is commonly used as an insulation material. Fiberglass is also often used as a reinforcement for composite structure because of it`s strenght and relatively low price. The emarging material is fiber-reinforced polymer (FRP) but the it is also commonly called just fiberglass.

HISTORY

Fiber glass production history

"Phoenicians, Egyptians, and Greeks did it; archeologists have found artifacts from all these civilizations laced with decorative glass filaments. In medieval Venice, artisans used finer and finer threads to adorn their glassware. As the filaments grew thinner, they became more flexible, though they were still thick enough to break if bent sharply."[18]

Fiber glass as known today was invented by Russel Games Slayter in 1938. It was primarily used as a material for filtering and as an insulation. Its market name "Fiberglass" has become a common name for the material.

"By 1940, Owens-Corning had managed to produce a glass-wool insulation that was less expensive than mineral wool (or rock wool), the most popular insulating material of the time, which is made by blowing steam through molten stone. The company's research advances coincided with the approach of World War II. In 1939 the U.S. Navy specified fiberglass as the preferred thermal insulation for all new warships.

Yet, even greater things were in store. Slayter and his team had also discovered that fiberglass embedded in various hardening resins could form a rigid, tough, lightweight, easily moulded material that

could replace plywood and sheet metal. [...] Tests showed that the tensile strength of Fiber Rainforced Polymer, whether reinforced with woven cloth, mat (compressed short fibers), or rovings, was greater than that of most metals."[18]

Us Army was also experimenting with other use of glassfibers. Few experimental planes were build from fiberglass composite during II World War.

After the war, many industries started to be interested in possible use for fiberglass. One of the first uses of fiberglass as a part of composite, was in boat construction. Boat hulls made traditionally from wood were very vulnerable to warp, leak, shed paint and were attacked by worms, bacteria and fungi. Fiber reinforced polymers eliminated all of these problems. They are still commonly used for boat and yacht production.

PROPERTIES

Fiberglass has very high tensile strength. Its fiber has higher tensile strength than steel wire of the same diameter while fiberglass has lower weight.

Fiberglass cloth has very good heat resistance. It retains approximately 50% of room temperature tensile strength at 371°C; approximately 25% at 482°C; with a softening point of 846°C and a melting point of 1121 °C.

It has high fire resistance, good thermal conductivity and good chemical resistance. Like glass itself, fiberglass cloth is highly resistant to attack by most chemicals.

Basically, fiber glass has in many cases very similar properties to regular glass. "It repels moisture; most acids and alkalis do not penetrate the filaments; it resists mold and mildew; it does not conduct electricity; and it doesn't decay, rust, shrink, expand, or burn." [19]

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APPLICATIONS

Areas where glass fibers are commonly used:

Building Insulation
Sport equipment
Boats, yachts
Aviation industry - glides, planes
Part of car body panels - and not so often for full car bodies
Furniture - especially chairs
Plastics reinforcement
Concrete reinforcement
Construction structures
Electronics

ADVANTAGES

Fiberglass cloth is lower in cost than many other fabrics for similar applications (insulation, composite reinforcement).

DISADVANTAGES

Fiber glass is not biodegradable. It is impossible to recycle when it is part of a composite. Glass alone can be melted, but it is not possible to separate it from a polymer in a composite structure.

FIBERGLASS PRODUCTION

Production process of fiberglass has not changed very much from the times of its invention.

Major ingredients of fiberglass are silica sand, limestone, and soda ash. Different varieties can consist of other ingredients e.g.calcined alumina, borax, magnesite etc.

Waste glass is used also as a raw material for producing fiber glass.

„Silica sand is used as the glass former, and soda ash and limestone help primarily to lower the melting temperature. Other ingredients are used to improve certain properties, such as borax for chemical resistance."[20]

Although fiberglass can be made directly from those ingredients, it is usually made from ready made marbles of raw glass. Using marbles has two purposes: first, they can be added to the melt at a controlled rate, which helps keep the temperature inside the reservoir of melted glass constant; and second, transparent marbles can easily be inspected for impurities. [21]

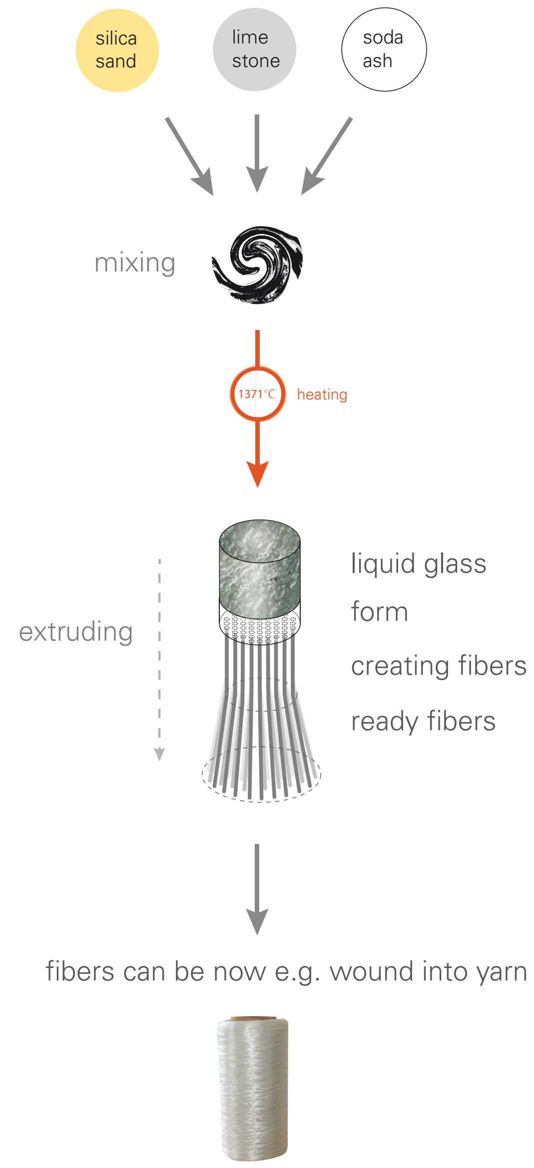
The glass is melted in an electric furnace and then forced through a perforated metal plate called a "bushing." The bushing is made of platinum or another exotic metal, because molten glass is so highly abrasive that most metals would be unable to resist it. The high melting point of Platinum - 3,200 degrees Fahrenheit - allows it to be heated to the temperatures needed to let glass, which melts between 1,800 and 3,800 degrees, flow through.

To form continuous filaments, the molten glass, after flowing through the tiny holes in the bushing, is attached to a winder and pulled until it reaches a diameter between 27 and 180 millionths of an inch (the smaller figure is about 1/100 the width of a human hair).

Hundreds of parallel filaments are gathered on a large steel drum, where they are combined into a fine, untwisted strand called a "sliver." The sliver is fed onto a spool, and from there it can be put through conventional textile processes, such as twisting or plying, and woven into cloth.

The strands can also be fed into another machine to make a heavy yarn or loose rope called a "roving."

A different process is employed to make short, noncontinuous strands used for non woven fabrics or insulation. "It uses a bushing with wider holes, which the molten glass passes through by gravity. As the strands emerge, high-pressure steam or compressed air is blown on them (Owens-Corning consulted the rocket pioneer Robert Goddard on the original design of the steam nozzles), yielding an explosion of tiny glass strands 8 to 15 inches long and about 220 millionths of an inch thick. They drop down to a conveyor belt and are collected for use in batts, rolls, or blankets." [22]



POLYMERS

Polymers are the glue that hold the fibers together in a certain orientation. Generally, the higher the polymer content, the harder the composite will feel (unless an elastic polymer like rubber is used) - and the higher the fiber content, the more flexible the composite. It might even feel soft like a textile.

Plants have natural polymers (cellulose, lignin, pectin) that hold the plant together. Pulping makes it possible to use these in composites, like paper.

Plastic polymers are grouped into thermoplastic or thermosetting types. Thermoplastics can be formed into a shape, then melted and reused in a closed loop system of production. They are commonly used to make reinforced plastics products that are injection or rotation-molded, like outdoor furniture. Thermosetting polymers cure by crystallizing, so once they are cured they cannot be melted and reused in the same form. Often, they are in the form of glues and used produce plywood or fiber board. They are also used in combination with glass and carbon fibers to make high strength, cured reinforced plastic products like motorcycle helmets or ski poles.

Biopolymers are polymers that biodegrade. They can come from either renewable natural or synthetic materials. Depending on the application, biodegradability might not be ideal or practical in use. Biodegradable polymers can come from starch, sugar, cellulose, or petrochemical based synthetics. We looked closely at corn based polylactic acid polymer (see linen-impregnated with PLA and a piece of PLA glue below). This study will explore creative possibilities and limitations of using conventional and emerging biopolymers combined with bast fibers in composites.

This study will look at creative possibilities and limitations of using conventional and emerging biopolymers combined with bast fibers in composites.

ADVANTAGES OF BIOPOLYMER IN COMPOSITES	DISADVANTAGES OF BIOPOLYMER IN COMPOSITES
Possibly biodegradable	Biodegradable may not be practical or appropriate, depending on the product.
Less toxic processing	Less tested, new field. Long term durability unknown.
Does not leach harmful chemicals into landfill.	Not manufactured on large scale, which means they cost more.
Some (as PLA) are thermoplastic, which means they can be reused in a closed loop cycle.	The melting point of some (as PLA) is so low that products may deform to easily from weather related or body heat.
Use no petrochemicals, and generally fewer overall compared with synthetics.	Some synthetics may still use fewer resources over the life cycle when compared with MIPS calculations (note: they do not include toxicity or weigh advantages of using renewable resources vs. nonrenewables)

PLA/ biopolymer

WHAT IS PLA?

Poly(lactic acid) or polylactide (PLA) is a biodegradable, thermoplastic, aliphatic polyester derived from renewable resources. PLA can be produced from corn starch (in the United States), tapioca products (roots, chips or starch mostly in Asia) or sugarcanes (in the rest of world).

At the moment, PLA is usually made in two stages. First, a source of starch or sugar, which could be an agricultural by-product, is fermented to produce lactic acid—the same substance made by the body during exercise, only in this case it comes from the bacteria exercising themselves in the fermentation process. In the second stage, lactic-acid molecules are linked into long chains, or polymers, in chemical-reaction vessels, to produce PLA. Due to the complicated process of making PLA, it is currently more expensive than other polymers, however, there are other manufacturing technologies currently being developed, to ease and simplify this process.

Like the petroleum-based biodegradable polyesters, PLA has many of the same undesirable mechanical properties, such as low heat deflection temperature. The polymer is also very brittle and has a low-melt strength leading to difficulty in processing. Consequently, most commercial applications using PLA require a synthetic rubber and/or acrylic additive to compensate for these deficiencies.

PLA is a sustainable alternative to petrochemical-derived products, since the lactides from which it is ultimately produced can be derived from the fermentation of agricultural by-products. PLA is more expensive than many petroleum-derived commodity plastics, but its price has been falling as production increases.

The demand for corn is growing, both due to the use of corn for bioethanol and for corn-dependent commodities, including PLA.

WORKING WITH PLA

PLA has similar mechanical properties to PETE polymer, but has a significantly lower maximum continuous use temperature. PLA can be formed by blow molding, injection molding, sheet extrusion, or thermoforming. It can also be blended with some petroleum-based polymers to improve heat resistance. Potential for compostability is lost, but that is not a drawback for objects that would not have been reasonably expected to be properly composted.

Polylactic acid can be processed like most thermoplastics into fiber (for example using conventional melt spinning processes) and film. In the form of fibers and non-woven textiles, PLA also has many potential uses, for example as upholstery, disposable garments, awnings, feminine hygiene products, and diapers. It has also been used in France to serve as the binder in Isonat Nat'isol, a hemp fiber building insulation.

PLA is currently used in a number of biomedical applications, such as sutures, stents, dialysis media and drug delivery devices. It is also being evaluated as a material for tissue engineering.

Because it is biodegradable, PLA can also be employed in the preparation of bioplastic, useful for producing loose-fill packaging, compost bags, food packaging, and disposable tableware.

PLA is used as a feedstock material in 3D printers such as Reprap and Makerbot..

TEMPERATURE LIMITS

The maximum continuous use temperature of PLA, before temperature-driven loss of mechanical properties becomes excessive, is that of 50 °C. The definition of excessive can vary between industry sectors, but exceeding this temperature will not necessarily cause degradation of the material.

Melting onset of PLA, the temperature at which some constituents of the material begin to melt, is 160 °C. However, the heat deflection temperature, also known as "heat distortion temperature," of PLA is 65 °C.
This is significant because it reflects the of retention of mechanical strength at elevated temperatures. It is used primarily for material comparison, but the exact value may be useful in design if referenced to guidelines (e.g. relating deflection temperature to thermoforming mold temperature).

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WORKING WITH PLA

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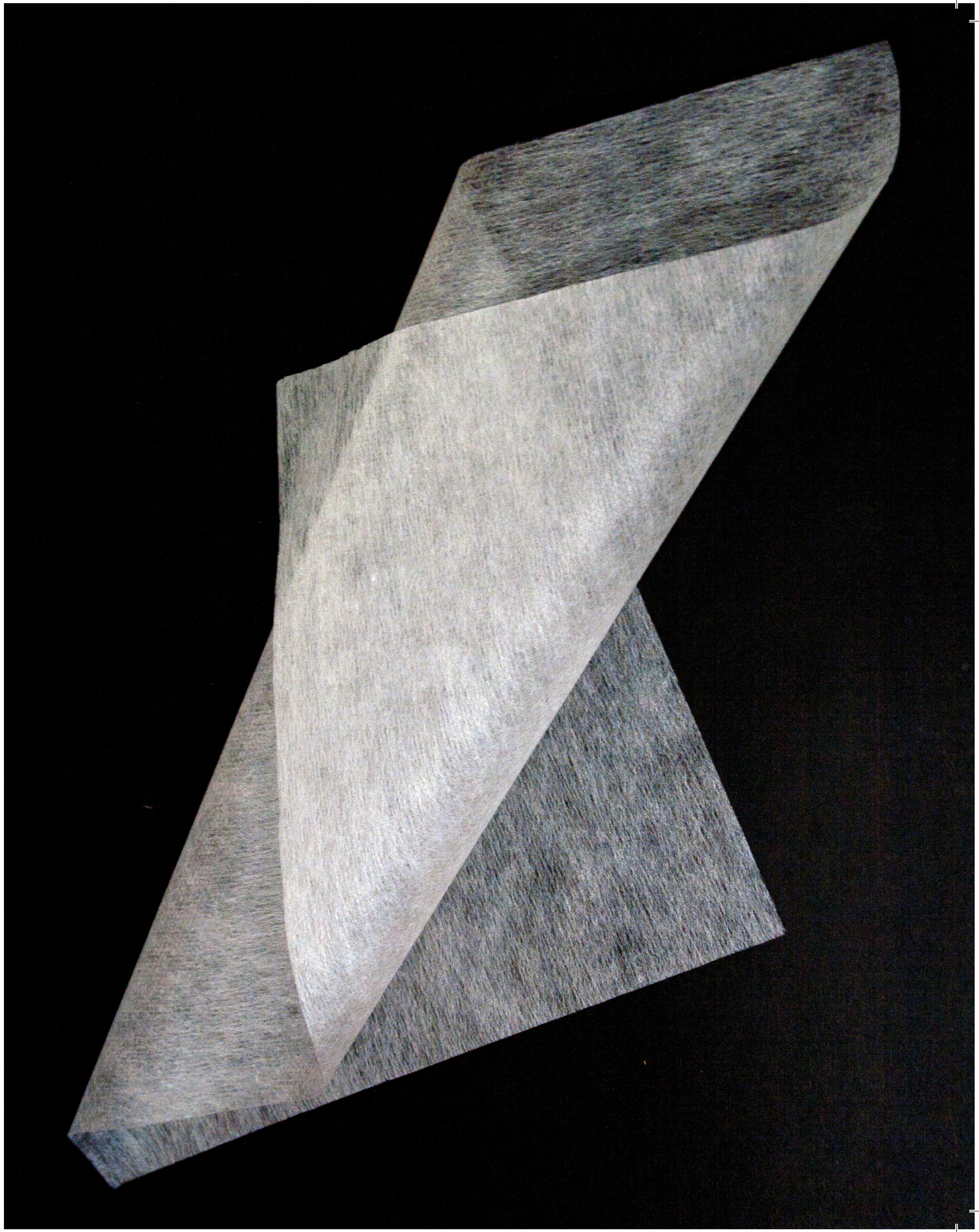

02 chapter

composites

MAN-MADE COMPOSITES/

This study categorizes composites into the following types:

Paper

Composite Textiles

Fiberboard

Reinforced Plastics

Plywood

ADVANTAGES OF COMPOSITES	DISADVANTAGES OF COMPOSITES
Lightweight with high strength (comparable to metal alloys)	Conventional composites are made from petroleum based fibers and resins which are non-biodegradable by nature
Can be formed into almost any shape	Repair is difficult and expensive, sometimes not possible
More corrosion resistant than metals	Production is complex, labor intensive, and difficult to inspect for flaws
Energy/fuel savings from reduced weight	High cost compared to non-reinforced plastics
Natural fibers and polymers can be substituted into composites, which are renewable resources and have the possibility of biodegrading.	Composites usually absorb moisture, and so need to be coated.
Long lasting	Long lasting

PAPER

Paper is perhaps the first bio-composite, originally made by the Egyptians from papyrus. Papyrus stems were disassembled, laid flat, woven in strips at right angles, and then hammered to join the strips by softening the cellulose polymer. Today's paper is made by smashing fibers with water into a pulp and then organizing the fibers onto a screen (flat) or shaped over a form until it dries. Common fibers used are wood, cotton, hemp, and linen. This process makes use of the natural polymers in the fibers to hold the fibers in a new (random) orientation.

Other polymers are sometimes added to paper to change its character (say, adding plastics to increase water resistance used in packaging). Opportunities for using paper exist for designers who want to make forms from alternative natural fiber papers (such as bast). They can also consider replacing petro-chemical based polymers with biopolymers. If polyethylene used in coated papers was replaced with a biopolymer, it could reduce plastic scraps in trash and compost. Coating paper with natural vegetable wax could be an alternative.

plate 3
K3 child chair by
Claesson Koivisto Rune

Two designs by Claussen Koivito Rune in 2010 combine wood pulp with the polymer PLA (made from corn starch), the Parapu compostable child's chair *(plate 3)* and the W101 lamp *(plate 5)*. Both can be thrown into the garden to compost at the end of life (say, when the child grows up). Pictured below is the Imprint chair designed by Johannes Foersom & Peter Hiort-Lorenzenfrom in 2005 *(plate 4)*. It uses a proprietary Celllupress material made from compressed plant fiber matts made from mixture of wood pulp, bark, spruce or coconut (and apparently using the natural cellulose as the binder).

plate 4:
Imprint stacking chair by Foersom/Hiort-Lorenzen

plate 5:
The W101 Lamp by Claesson Koivisto Rune

PLYWOOD

Plywood is one of the most commonly used man-made composites. Technically, plywood is a composite made from bi-directionally oriented reinforcement fibers set in a glue resin polymer. Designers can consider substituting the inner plies with bast fiberboard cores, adding fiber textiles as reinforcement inside traditional plywood, as well as substituting biopolymer glues for traditional formaldehyde based resins. Columbia Products, a major producer of plywood in the U.S. is now using soy based glue for its plywood.

The natural properties of fibers in wood cause the width of a solid wood plank to change considerably depending on the ambient humidity (wood moves across the grain). The composite plywood takes advantage of the one way available to cabinetmakers to stop wood from moving. Sliced thin enough, the strength of the glue becomes stronger than the fibers' ability to expand and contract. Thin slices of wood are called veneer and sold in sheets. Plywood panels are made by stacking these thinly sliced sheets of wood (veneer), alternating the grain direction 90 degrees between each layer to create large dimensionally stable flat panels.

plate 6:
Eames bent plywood Chair = Work of Charles and Ray Eames by Donald Albrecht, 1997

Plywood panels were developed as an alternative to traditional frame-and-panel construction. Until plywood was perfected, carpenters made furniture from wood panels slotted into grooves. Panels floated within dimensionally stable frames. Before plywood, this was the only reliable method of constructing long lasting furniture, as the structure was designed to allow wood to move without compromising the strength of the joints. Plywood makes it possible for designers to use large stable panels without the need for a frame.

In the 1950s, glue polymers were quickly developing, and designers began experimenting with the forming possibilities available in plywood. Designers began making organically formed shapes by laminating veneer. Veneer layers are stacked with glue in between, then the entire stack is pressed over a form until it cures and holds the shape as a composite. Since the grain follows the form, this construction is stronger than simply cutting the shape from a solid log (where grain will sometimes be oriented in the short direction and can break easily). U.S. designers, Charles and Ray Eames, for example, developed strong plywood splints during World War II whose organic shape conformed to the human body for maximum support. They later used these experiments to develop an organically shaped plywood chair. Compare opportunities in plywood from an exhibition catalog of the Eames' work *(plate 6)* versus an early Finnish-made solid wood chair carved from a single log *(plate 7)*.

plate 7:
Finnish-made solid wood chair carved from a single log

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FIBERBOARD

Similar to plywood, fiberboard composites were developed for more specialized uses or cost requirements. They are most commonly made from randomly oriented chipped or ground wood fibers set in urea formaldehyde resin polymer. Particle board (low density), medium density fiber boards (mdf), and oriented-strand boards are short fiber versions of plywood. They were developed to be used as substrates (under a skin). While they are consistent in color and density, they are most commonly covered by finish, veneer or plastic laminate. One fiberboard (Masonite) is made solely from wood chips - blast steamed, heated and pressed into boards. It is a hardboard panel that relies on the wood's natural cellulose to bind the fibers, the same as paper.

Manufacturers are experimenting with using other chopped plant fibers for these composites, as the fibers needed can be short or even ground. Waste fibers from agricultural processes are a focus, as they are inexpensive and the individual plant fibers are often stronger than wood fibers. Bast fibers used for these composites can either be made from plants grown specifically for fabric fibers (long fibers) or from agricultural waste (short fibers). Below left is the Compos Chair designed by Samuli Namanka *(plate 8)* and developed with manufacturer Piiroinen in 2009. It is made from a cast fiberboard composite of waste flax fibers (leftover from linseed oil production that would otherwise be burned) set with polylactid acid (or PLA), a polymer made from corn starch.

plate 8:
Samuli Namanka fiberboard chair

REINFORCED PLASTICS

Reinforced plastics in household products are commonly made from petro-chemical based plastic polymers combined with glass, carbon, or aramid fibers (man-made but not petro-chemical based). The fibers are placed into the polymer by various means. One, they can be mixed into the polymer in its liquid state then pressed into sheets or injected into a form. Fibers will be randomly oriented in sheets or, in the case of injection molding, fibers will orient themselves generally in the direction of the material flow while being injected into the mould. In another process, woven textiles are saturated with polymer and then allowed to stiffen.

Reinforced plastics were developed in the 1940s as a replacement for formed metal. They are lighter weight and sometimes even stronger than metal. Compare metal armor *(plate 11)* to the fiberglass-reinforced Shoei Multitech motorcycle helmet *(plate 10)*. Fiber reinforced composites add surprising strength. They allow structures to look delicately elegant while still retaining strength, as demonstrated by Outfeet's fiber reinforced prosthetics designed by Aviya Serfaty. *(plate 9)*

plate 9:
Outfeet prosthetic by Aviya Serfat

plate 10:
Multitec Shoei Motorcycle helmet

plate 11:
metal armor

Plastic polymers used in plastic composites are grouped into thermoplastic or thermosetting types, as described in the polymer section.

The advantage of thermoplastics is they can be melted and reused, though less easily if reinforced with fibers. Some thermoplastics (such as PLA can be recycled in combination with the fibers in a closed loop. Further studies are needed to determine how much the fibers deteriorate or get shorter with each reuse. Common thermoplastics used in household product composites are polypropylene, polyethelene, polyamide (nylon), polyethylene terephthalate (PET), acrylic, polyvinyl chloride, polystyrene, polytetrafluoroethylene ("Teflon"), and acrylonitrile butadiene styrene (ABS).

Common thermosets used in composites are often in the form of glue, like urea resin, polyurethane, epoxy, polyester, and vinylester. Advantages of thermosets is that they take a form permanently and will not burn or melt. They are malleable until they cure and then hold their final form by cross-linking. Since they cannot be melted after curing, they can not be recycled unless ground as filler. Advantages are they have a smooth surface finish and can be melted down to use again and again without degrading. Sometimes they are less heat resistant and can deform if they get too hot. One early reinforced modern plastic was actually made using natural fibers. Phenolic ("Bakelite") is a thermoset created in the 1940s made from layers of paper or cloth (such as cotton or linen) impregnated with phenol and formaldehyde. Later reinforced plastics evolved to use man-made fibers as they were developed with specialized characteristics that could be controlled in a laboratory.

Two classic chairs made from fiberglass reinforced polyester are Charles and Ray Eames Shell Chair (made from fiberglass reinforced polyester, a thermosetting polymer) and Verner Panton's *(plate12)* entirely plastic fiberglass reinforced polypropylene chair made from thermoplastic polypropylene reinforced with fiberglass, a thermoplastic polymer.

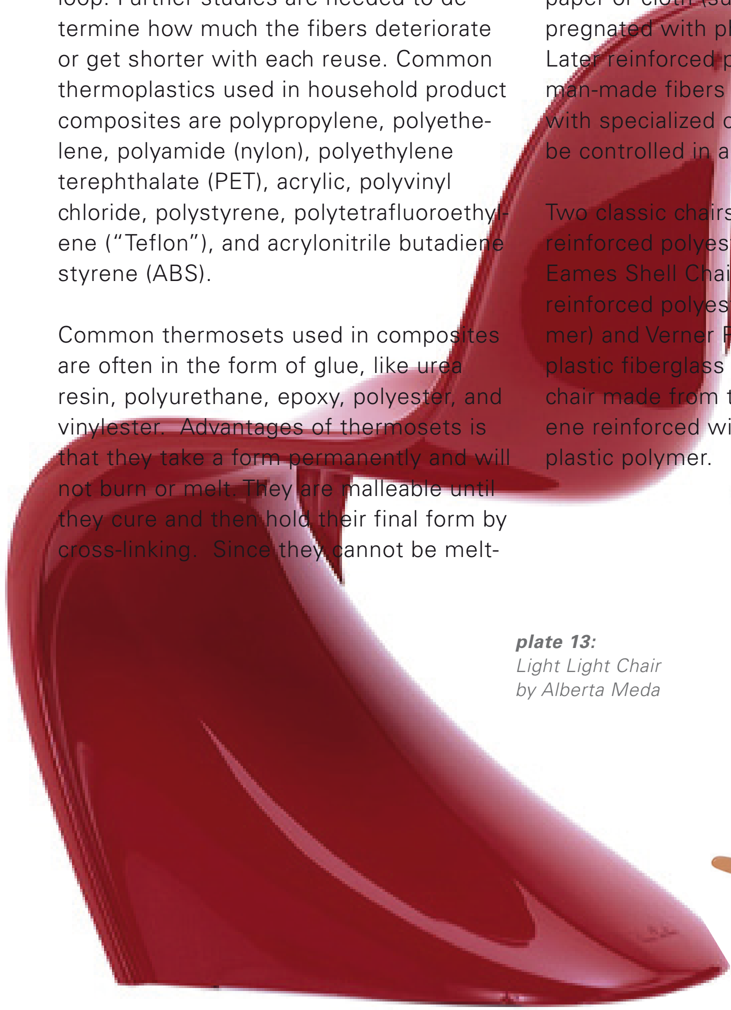


plate 13: *Light Light Chair by Alberta Meda*

plate 12: *Verner Panton fiberglass chair*

plate 14: *Knotted Chair by Marcel Wanders*

Designers must choose the orientation of the fibers within reinforced plastics depending on the forces placed on a product. Longer fiber (used most commonly for woven textiles) are stronger than short fiber randomly-oriented fiber structures, but random orientation gives more opportunity for organic form. As the tensile strength of some bast fibers is comparable to glass fiber, opportunities exist for designers to use bast fiber textiles or randomly-oriented needle-punched (felted) fibers as a replacement for glass, carbon, or aramids ("kevlar"). Contrast the Panton and Eames chairs to Light Light, designed by Albert Meda in 1987 *(plate13, left)*. It is made from woven carbon fiber saturated with thermosetting polyester. The epoxy-saturated aramid fiber chair Knotted Chair *(plate 14, above)* was designed by Marcel Wanders in 1995.

Bast fiber alternatives were used by Francois Azambourge, who worked with a producer to develop a composite for his Lin 94 chair in 2008. The final design is cast from a composite of flax, 80% plant-based/epoxy resin. He chose flax because it is lighter than glass fiber and requires less energy to produce than both carbon and glass fibers.

COMPOSITE TEXTILES

Textiles and filaments can be combined with polymers to create textiles with improved characteristics, such as tear resistance, water repellence, shape-holding, translucency, or elasticity. Fibers can be woven into textiles and impregnated with polymer, mixed with fibers and sprayed in a random orientation, or mixed with polymer as needle-punched felt and heated to hold shape. The structural textile for hot air balloons needs to hold air as well as let some air pass through, be flexible, and have a very high tensile strength. The fabric is generally made from either nylon or polyester with polyurethane as a sealer (polymer) with the addition sometimes of neoprene or silicone and various ultraviolet inhibitors. A characteristic of linen woven textiles are their crispness, which means they holds shape well. Opportunities exist for using fabrics as structural or sculptural textiles, as Rachel Philpott does in her textile design *(plate17)* or Mika Tolvanen does in his recycled PET felt basket *(plate16)*.

In some applications, the fiber filament is also a self-bonding polymer. George Nelson's Bubble Lamp *(plate15)* and also the Taraxacum Lamp by Achille and Pier Giacomo Castiglioni, for example, use nylon as both fiber/polymer to create a light diffusing elastic textile, spraying it onto a rotating steel frame in layers until the frame is covered in semi-solid fiber. The fiber/polymer then tightens as it cures to form a translucent, strong, flexible, and pre-stressed textile over the steel armature. The same idea is used in spray on fabric developed by Dr. Manel Torres (fabric is formed by the cross-linking of various fibers sprayed directly onto the human body or used in any application where spray fabric is appropriate, and it is available in varying colors, textures, and properties. An advantage of this composite is its easy repairability. The customer can repair by simply spraying on more fiber.

plate 15: *George Nelson Hanging Bubble Lamps*

plate 16: *Restore Basket by Mika Tolvanen*

plate 17: *Origami textile by Rachel Philpott*

03 chapter

labels & resources

LABELS/ meaning

"The ones who shop ethically conscious, are concerned with the effects that a purchasing choice has not only on themselves, but also on the external world around them" (Harrison, 5) .In other words, we have to make people aware that shopping, and buying an item, is like a political voting for the product. You say "Yes" to the item, accept the way it is produced and what it contents. This includes with the consumers choice, that he accepts and agrees the way the product is made. The more consumers are asking for good products, the more the market will grow. Hence, the responsibility is neither only on the producers side, nor the designers, the consumer has a huge chance and task to wish for well-designed products in a sustainable manner.
"Design is key—to be effective, a label must be informative and intuitive enough to guide good choices without confusing shoppers."(Centre for American Progress)

Öko-Tex standard
The International Commission on Research and Tests for Ecological Textiles (abbreviated to Öko-Tex) created the 'Confidence in Textiles' logo in 1992. The symbol shows that a product has been tested according to Öko-Tex Standard 100 and offers a guarantee of respect for limits on the use of the following pollutants: pesticides, formaldehyde, copper, cobalt, chrome, 2,4-D and 2,4-T.

Öko-Tex Standard 100 is concerned only with health protection in respect of the finished product. It does not apply to production; in other words it does not take into account ecological criteria for cotton cultivation, processing or work conditions.

Toxic substances
Toxic substances defined under this standard are those:

_that are present in a textile product or garment in quantities superior to defined limits.

_that are present during normal use in quantities superior to predefined limits and that may have any harmful effect on humans.

_that, based on present knowledge, may turn out to be harmful to human health

_The label "Confidence in Textiles: tested for harmful substances according to Öko-Tex standard 100" does not constitute a quality standard and applies only to the finished product. It takes no account of performance aspects such as durability, wearability, physical properties or flame resistance.

Öko-Tex standard 100 Tests
The Öko-Tex standard 100 tests for the following and guarantees that their prescribed limits have not been exceeded:

PH value, formaldehyde, extractable heavy metals, arsenic, lead, cadmium, chrome, cobalt, copper, nickel, mercury, pesticides, pentachlorophenol, colorants as carcinogens or allergens.

Also tested for are the fabric's resistance to: water dyes, dry and wet friction, saliva and perspiration as well as for any possible emissions of volatile substances or undesirable odors.

Today all of Switcher's suppliers are certified according to Öko-Tex standard 100. We are now working on level 1000, which is a new certificate dealing purely with ecological aspects.

more info: http://www.switcher.ch/english/about-switcher/switcher-norms-and-certificates/oeko-tex-100.php

CRADLE TO CRADLE CERTIFICATION:

Cradle to Cradle® Certification is a multi-attribute eco-label that assesses a product's safety to humans and the environment and design for future life cycles. The program provides guidelines to help businesses implement the Cradle to Cradle framework, which focuses on using safe materials that can be disassembled and recycled as technical nutrients or composted as biological nutrients. Unlike single-attribute eco-labels, MBDC's certification program takes a comprehensive approach to evaluating the sustainability of a product and the practices employed in manufacturing the product. The materials and manufacturing practices of each product are assessed in five categories: Material Health, Material Reutilization, Renewable Energy Use, Water Stewardship, and Social Responsibility. (http://mbdc.com/default.aspx)

For Cradle to Cradle certification standards see: http://mbdc.com/detail.aspx?linkid=2&sublink=9

ISO Standards:

They are standards that many companies try to meet in order to better their business, quality, and service. ISO standards simply said are a set of international standards that can be used in any type of business and are accepted around the world as proof that a business can provide assured quality.

ISO standards play a huge role in raising levels of quality, safety, reliability, efficiency and interchangeability - as well as in providing such benefits at an economical cost.

ISO is the world's largest developer of standards, and this means they reach far beyond simply the technical world. ISO standards also have important economic and social repercussions, which mean they effect even that which is far from technical.

What are some of the benefits:

1. They provide governments with a technical base for health, safety and environmental legislation. They can do this by setting specific guidelines, which the government can then implement into inspections and safety specifications, and can do so at minimal cost and minimal risk as these standards have been tested and set by ISO.

2. They are useful for structuring and starting new technical companies. By knowing the standards that other companies are meeting, new companies can

emerge competitively as they too can meet these internationally known and respected standards.

3. ISO standards are a shield, or a safeguard to consumers, and users in general, of products and services. ISO standards are simply a way of ensuring a certain quality of life is maintained.

4. ISO standards are a safety net. Things for well, have less problems and security issues when there is a specific standard of quality they must meet.

ISO standards are there to make the development, manufacturing and supply of products and services more efficient, safer and cleaner, which benefits all.

www.ISO.org

IVN Naturtextil

Used mainly for fashion and shoes made out of natural fibres.

Publisher of the IVN label is the "Internationale Verband der Naturtextilindustrie" (IVN) – international association of the natural textile industry. Interested producers will send them a proposition after which the company will be controlled regarding the delivery of goods, as well as social- and environmental standards. After fulfilling those criteria, the producer will be certified for one year terminable.

Criteria: You get certified with the "IVN NATURTEXTIL BEST" if your products and fibres are produced following the highest environmental and social responsible factors. E.g.: 70% to 95% of the fibres needs to be from controlled ecological farming, prohibit the use of polluting production- and upgrade methods as well as deny special substances like formaldehyde, metal complex colours and synthetic colours with an AOX-level over 5%. Separate storing form conventional produced items. Social responsibility including deny child- and forced labour, discrimination and guarantee regulated working hours.

http://www.naturtextil.com/

G.O.T.S.
Global Organic Textile Standard

G.O.T.S. is a relative new label, founded in 2008, aiming to create an international Standard for the textile-industry, that consumers can immediately identify. Responsible for the development was the (IVN) – International association of the natural textile industry which took the standards of the IVN NATURTEXTIL BEST over.

GLOBAL ORGANIC TEXTILE STANDARD

Criteria:
Clothes certified with the G.O.T.S. label has to consist to 90% of natural fibres, whereof 70% has to come from biological farming.

Organic certification of fibres on basis of recognised international or national standards (e.g. EEC 834/2007, USDA NOP)

For bleaching while fibre processing only oxygen is allowed.

All chemical inputs (e.g. dyes, auxiliaries and process chemicals) must be evaluated and meeting basic requirements on toxicity and biodegradability/eliminability

Colouring and Printing only with environmental harmless substances. Colouring with toxic heavy metals or AZO-colours is not accepted.

For Upgrading the textile (e.g. crease-resistant or waterproof) there may not be worked synthetical additives. They may be considered for softening or felting. Regarding the social standards, they follow the criteria of ILO (International Work-organisation) Meaning there is no child or forced labour, abuse or discrimination. They have to ensure fair salary, work safety and freedom of association.

http://www.global-standard.org/

DIRECTORY/ online info

PESTICIDES

An extensive guide to pesticide toxicity and classification is published by the World Health Organization:
http://www.who.int/ipcs/publications/pesticides_hazard_2009.pdf

New Agriculturist
http://www.new-ag.info/developments/devItem.php?a=16

TOXICITY

Evaluation of the toxicity of carbon fiber composites
http://www.ncbi.nlm.nih.gov
pubmed/2753009

TEXTILES

technical textiles by Subhash Anand
http://books.google.fi/books: Handbook of

Dupont: Information on Kevlar
http://www2.dupont.com/Kevlar/en_US/index.html

Kevlar Technical Guide
http://www.linnovision.com/files/wordocs/KEVLAR_Technical_Guide.pdf

PDF File on Kevlar
http://www.nafaa.org/kevlar.pdf
P|lastics

Speedliner on Kevlar
http://www.speedliner.com/Websites/bearcat/Files/Content/158508/6.%20MSDS-Kevlar.pdf

Milk, Soy and Bamboo Fibers
http://www.bamboo-china.com/product/milk-fiber-top.html

Polyester Vs. Cotton
http://coralrose.typepad.com/my_we-blog/2008/07/polyester-vs-co.html

General Information on Hemp
http://www.binhaitimes.com/hemp.html

Handbook of technical textiles
http://books.google.fi/books:Cotton
http://www.cottoninc.com/

Movie on Linen
http://vimeo.com/16474921

From Flax to Linen
http://www.libeco.com/en/about-linen/from-flax-to-linen.aspx

PDF on technical fabrics from linen
http://www.libeco.com/en/about-linen/from-flax-to-linen.aspx

Linen
http://oecotextiles.wordpress.com/2010/06/30/linen/

PLASTICS

Glossary of Bioplastic Terms
http://www.mirelplastics.com/environmental/default.aspx?ID=1507

Information on PET
http://www.plasticsinfo.org/Main-Menu/MicrowaveFood/Need-to-Know/Plastic-Bev-Bottles/The-Safety-of-Polyethylene-Terephthalate-PET.html

Polyethylene pricing
http://www.icis.com/v2/chemicals/9076425/polyethylene-terephthalate/pricing.html

Information for PET
http://www.slideshare.net/nparker13/pet-bottles

COMPOSITES

Research on Biocomposites
http://www.bath.ac.uk/ace/biocomposite-materials/

GENERAL INFORMATION

Wikipedia
http://en.wikipedia.org

Design Dictionary
http://www.designdictionary.co.uk/en/kevlar.htm

Wiki Answers
http://wiki.answers.com/Q/How_much_does_Kevlar_cost_per_grams

CompoBastFiber Blogg
http://compobastfibers.posterous.com/

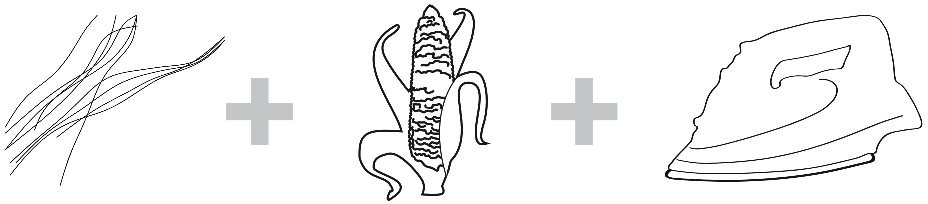
04 chapter

Prototypes

PROTOTYPES/ the insole

INSOLE

Inspired by wool insoles used for the winter came the idea of making a Hemp and Flax PLA insole. Hemp and PLA were taken together and matted as sheets. The foot was traced to create a pattern and then cut out for both right and left foot. On the matted Hemp and PLA the pattern was placed and cut leaving a seam of approximately 1" all around. The iron was adjusted to the highest setting, Cotton, at an approximate of 193C. Wax paper was placed on top of the mat. Two sets of mats where used and a sheet of PLA was placed in the middle. Using two sets gave it the desired thickness. Finally, the pattern was placed on the mat and cut out to the exact shape. At the end the insoles where tried out and used. In conclusion the draw back of the insoles was the flakiness of the fiber and short durability; but at the end it served the purpose of heating the foot.



Fibers (Hemp, Linseed) + PLA (corn based) + Heat (>170 - houshold Iron)

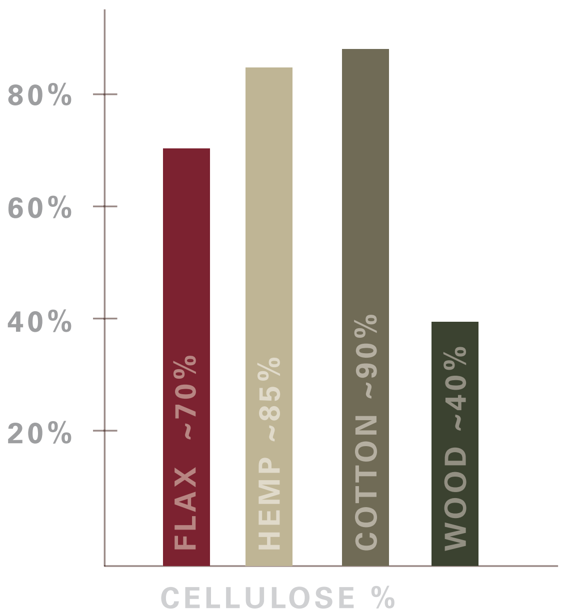
the shoe

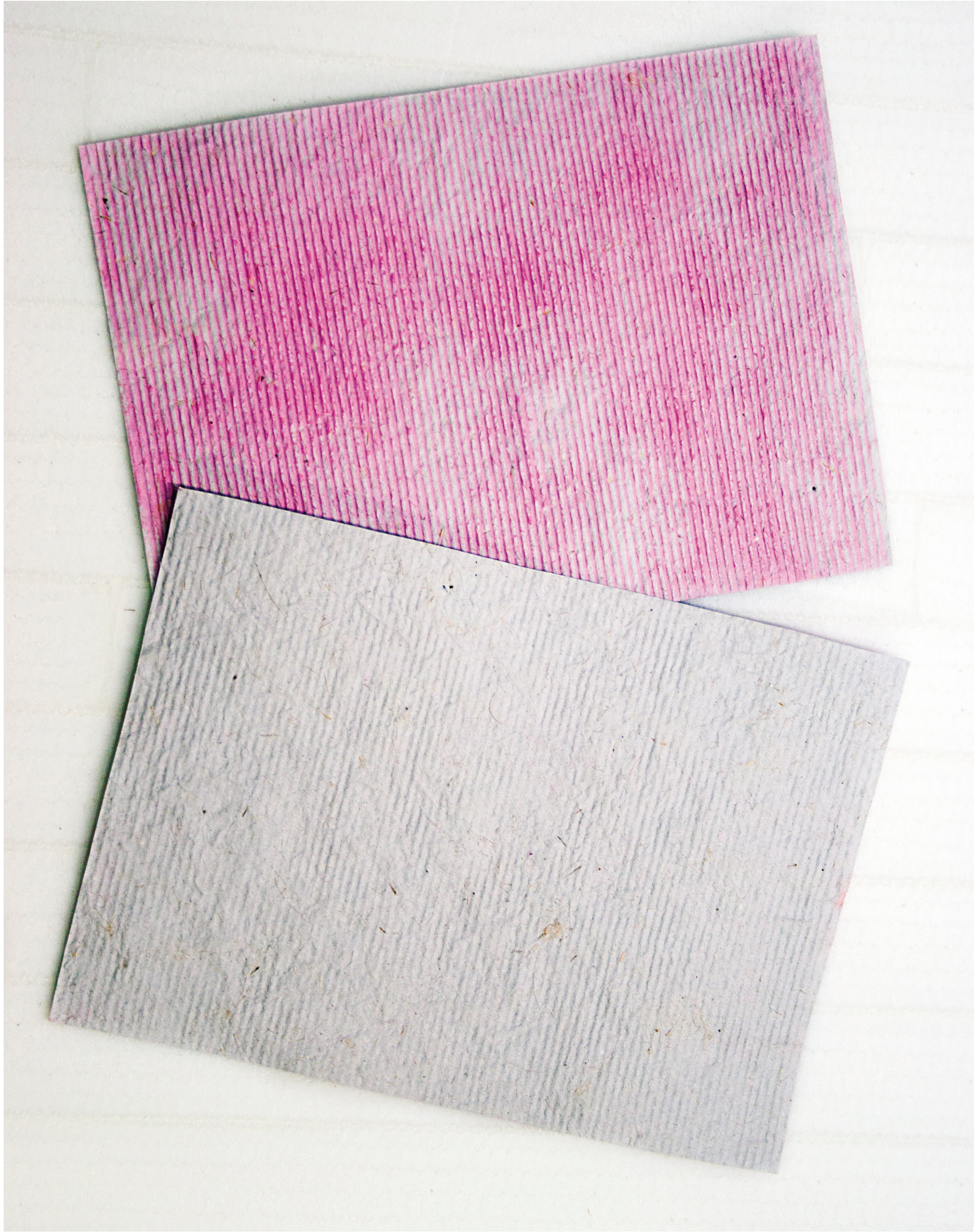
BOOTY/ SHOE

In the light of developing a sustainable shoe, the Hemp Booty was created. Firstly a "last" (wooden show form used to mold a shoe to a determined size) was used to follow the contour of the shape and used the "resist" method (creating a whole boot using the last as a mold). The contouring of the Booty was done directly on the last, using a mat of Hemp and PLA with heat and placing wax paper on top of the mat. When the desired shape for the base of Booty was done, then it was taken off the last. Following the base more matting was added. The heel was made with urea, formaldehyde resin (the resin will be substituted with vegetable wax), and hemp fibers. It was then casted at 170-degree heat, using a carton mold, finally chiseling it to the desired shape. Finally the heal was added to the Booty, gripped by using pure PLA sheets.
In conclusion the Booty was designed as a starting point, where eventually it can become a reality. It is a "work in progress"

PROTOTYPES/ paper+packaging

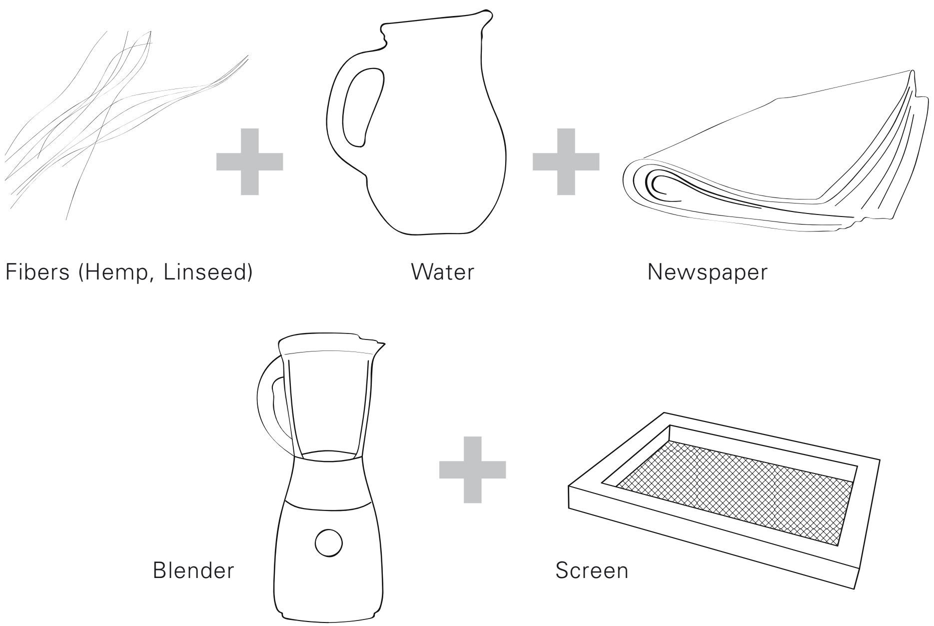
Inspired by the huge amount of paper waste that results from the packaging and advertisement industry, we wanted to try for ourselves and put to new use this waste and explore its suitability for quality packaging. Through research, we discovered that hemp and flax fibers have a higher content of cellulose than wood, which is the primary base in paper production, and they therefore serve as suitable replacements for wood fiber. This allows paper produced from flax and hemp fibers to be recycled more times than that produced out of wood. This would save resources and energy invested in deforestation, which in itself is very damaging to the environment.

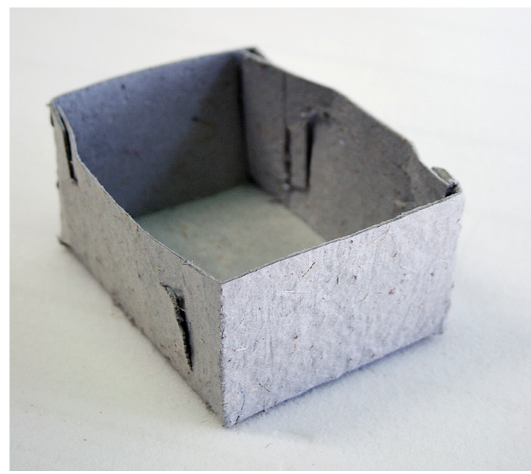




PROTOTYPES/ paper+packaging

In our paper experiment, we used recycled newspaper and flax and hemp fibers. The pulp was made by mixing these ingredients in a blender with water. Afterwards, we poured the pulp on a screen to dry with the aid of sponges, and we further allowed the fibers to set and harden into paper. Through trial and error, we discovered that the lesser amount of fibers used resulted in a more flexible paper. However, the fibers increased the strength of the paper, and in industrial paper production, the required machinery would refine them for higher quality products. Such products are available on the market, but only on a very small scale.

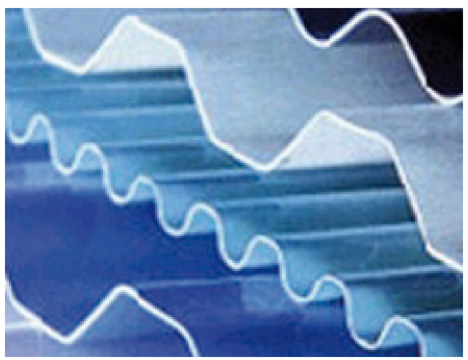




PROTOTYPES/
flax fiber panels

FLAX FIBERS (SHORT MATTED AND LONG WOVEN) + UREA RESIN + 80°

In 1948, Charles and Ray Eames worked with glass manufacturer Owens-Corning to experiment with a new material called "fiberglass." They sought to use this material (previously considered more appropriate for such industries as automotive and aerospace) to make a household product.



In this same spirit, I explored opportunities for replacing glass fiber with strong, renewable bast fiber to create similar formed components. I chose flax fiber, as I have ready access to both the short waste fiber and textile in Finland. I took a profile from common fiberglass roofing panels (which gain rigidity from both fiber reinforcement and being formed into engineered shapes). I made a mold over which I could vacuum form samples of this shape from different combinations of fibers and polymer. Because I was unable to obtain adequate PLA or soy resin, I produced my test samples from urea resin polymer and varied only the fibers.

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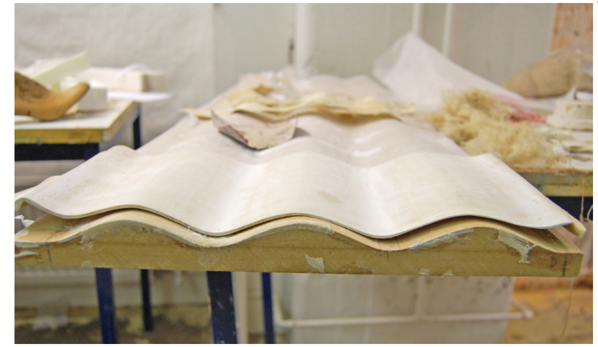
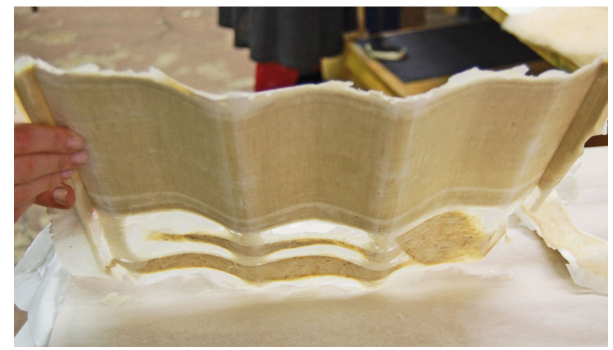
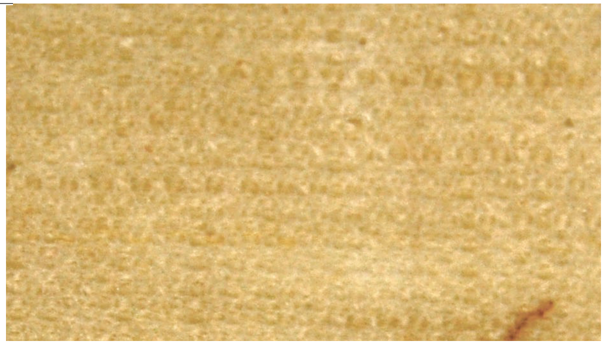
RESULTS

1 layer of nonwoven mat (randomly-oriented short fibers) impregnated with resin:

- Complicated to obtain even thickness when making thin formed sheets.
- Mold should be 2 part (male/female) for even surface finish on both sides.
- Can be sanded and painted if desired.
- Not as strong as impregnated woven fibers, but much less expensive material cost.
- Can use waste fibers from linseed production that would otherwise be burned.
- If made w/ thermoforming resin (such as PLA), it can be melted, including fibers, and reused to make the same composite in a closed loop. This type can also biodegrade.
- If made w/ thermosetting resin (such as soy-based glue), composite cannot be reused in closed loop production but can be biodegradable.







5 layers of woven textile (bi-directional long fibers) impregnated with resin:

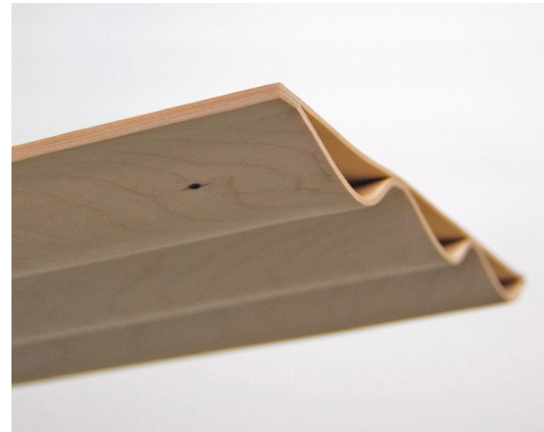
- Longer fibers made a strong, still flexible, composite in length and width.
- Woven textile sheets are easier to assemble into even layers when pressed.
- Linen textile is expensive.
- Textiles cannot be extracted for reuse in closed loop production.
- If made with PLA or soy resins, biodegradation is a possibility.
- Can be sanded and painted if desired..
- Can be covered with a “skin” of veneer or textile if desired.
- Textile sheets can be alternated with wood veneer layers to create a plywood composite.

The look and feel of linen composite is limiting aesthetically, so I experimented with possibilities for adding a “skin” of wood or needlepunched linen felt (undyed and dyed). Since it can be sanded, painting the composite is also a possibility. However, because of its strong texture, the woven composite would require use of filler to obtain a professionally smooth surface finish.

wood + linen plywood composite

WOVEN FLAX TEXTILE (3 LAYERS) + .6 MM BIRCH VENEER (5 LAYERS) + UREA RESIN + 80°

Wood fibers are strong in length but tend to crack along the grain. Bi-directionally woven linen textile inserted between the wood layers adds stability perpendicular to the wood fibers while still being thin enough to take a form (unlike a stiff layer of wood veneer oriented perpendicular to the curved shape). It also allows the plywood to flex without breaking across the width. Shaping the bottom layer adds thickness needed to keep the shelf straight when weight is applied, lighter than a solid plywood panel of the same thickness. Aesthetically, wood has a warm, familiar look and feel. The linen/wood composite can be sanded and finished the same as conventional plywood. Cost of materials and production would be higher, but the expense might be appropriate where thinness is desired for elegance or to reduce weight.



Shelf weighs 1.5 kilos and flexed just 7mm with 50 kilograms of weight in center.

CONCLUSION/

Bast fiber based bio-composites are already being embraced by the car industry. Henry Ford first built a hemp car in the 1940s but the experiment was shelved after petrol-based plastics became the most adopted and readily available. Toyota, Daimler Chrysler, and Ford are carrying his work forward today, developing biocomposites for use in their cars. Composites are often lighter in weight and structurally superior to conventional metal panels (Biocomposites in Automotive Manufacturing: Replacing One Car Part at at Time, by Rachel Campbell). "Four key factors have driven Toyota's research into bio-based materials: 1. Environment-friendly technologies, 2. Increasing speed of dismantling, 3. reduction of use of materials toxic to humans or the environment, and 4. reduction of PVC use (ibid: Campbell from Toyota Motor Company, 2006)." Not mentioned by Toyota, another advantage to using biocomposites is not having to pay the price of disposal for industrial hazardous waste made while producing cars with conventional plastics (ibid: Campbell).

Designers of products must experiment with emerging bio-plastics in order to guide material scientists and manufacturers toward which useful bio-materials are developed in the future. Challenges of acceptance will gradually disappear as designers specify the materials, consumers demand them, as manufacturers feel comfortable investing in machinery, and also as the necessity of replacing petrochemical based materials accelerates.

Ultimately, the Compobast Fiber Guide is a glimpse onto the world of sustainable materials. The information shared in this guide is an example of other options available when choosing the most sustainable materials for one's product. We must make the assumption that the options presented in this guide will be readily available and will soon be available as substitutes for conventional impactful materials. While this guide cannot help a designer to answer the question -- should I make more products for an already over saturated market of "stuff?" -- it does offer knowledge that can help designers make a thoughtful choice when choosing materials for what does get made.

The power behind a sustainable material is to create a solution to an already existing problem, hence to not add more weight to the problem. The examples given are just a beginning to the vast possibilities for using biocomposites. As authors William McDonough & Michael Braungart state clearly in Cradle to Cradle: "Design is based on the attempt to fulfill human needs in an evolving technical and cultural context." An evolution with nature rather than against is what we attempt with this guide.

DESIGNER? consider:

As a designer have you considered any of these questions, we have:

DESIGN

1. How can you use intelligent design to reduce the social and environmental impact of a product's lifecycle?
2. Do you consider the environmental effects of the colors and prints you choose for your collection?
3. Can you create a longer-lasting and better-functioning product, thereby reducing the need to replace it?

RAW MATERIALS

4. How much water does it take to produce your fabrics?
5. Are you aware of the sustainable alternatives to the raw materials you are currently using?
6. When selecting your fabric range, do you think about the end-of-life stage, such as the implications of disposal?

PRODUCTION

7. How well do you know your supply chain?
8. What are the social costs of your production process?
9. Have you ever considered using recycled pre-consumer/post-consumer waste in your collection?

PACKAGING AND TRANSPORT

10. Are you able to reduce the amount of solid and hazardous waste in your packaging?
11. Have you considered a local supply chain to decrease mileage in the production process?
12. Could you reduce the weight and volume of a product by using fewer or lighter materials to optimize transportation?

CONSUMER USE

13. How durable are your products; is it possible to increase their longevity?
14. How can you encourage the customer to form an emotional attachment to your product, thereby discouraging disposal?
15. How does your product need to be cleaned and what impact will this have on the environment?

END OF LIFE

16. Can the product have a second life?
17. Could you offer an upgrading and/or a repair service to your customer?
18. Can you reduce the waste impact of disposing your product by making it recyclable or biodegradable?

GLOSSARY/ compendium

ORGANIC - `There is no "official" definition of an organic compound`. One of the definition is that Organic compounds are compounds that have carbon in it. The others are much more complicated but basically it is the carbon that defines the organicness of a compound. In many cases however it`s hard to define either the compound is organic or not. There are historical reasons for that and many ways to classify it exists the chemistry. according to wikipedia: most carbon-containing compounds are organic, and most compounds with a Carbon-Hydrogen bond are organic. Not all organic compounds necessarily contain Carbon-Hydrogen bonds (e.g. urea).

BIODEGRADING - The degradation of the material from naturally occurring microorganisms, such as bacteria, fungi, or algae, over a period of time. Source: ASTM, Alteration in the chemical structure of a substance, brought about by biological action, resulting in the loss of a specific property of that substance. Ultimate biodegradation (aerobic) is the level of degradation achieved when the test compound is totally utilized by microorganisms, resulting in the production of carbon dioxide, water, mineral salts, and new microbial cellular constituents (biomass). (...) Source: EPA OPPTS 835.3110 and OECD Guideline

COMPOSTING - A managed, agricultural process in which organic materials, including animal manure and other wastes, are digested aerobically (with oxygen) or anaerobically (without oxygen) by microbial action. Composting can be done successfully on a large scale by farmers and waste management companies, or on a small scale at home. When composting is carefully controlled and managed and the appropriate conditions are achieved, the high temperature generated can kill most pathogens in a few weeks.
Source: FDA

REINFORCEMENT FIBERS - Fibers being part of a composite which role is to give higher tensile strength and elasticity to the structure. It prevents the structure form cracking

LIGNIN POLYMER - Chemical compound derived from wood, being an integral part of the secondary walls of a plant. Major role is to strenghten the wood.

NATURAL COMPOSITE STRUCTURE
is what gives wood tensile strength and makes it a popular building material.

ENGINEERED MATERIALS sometimes separating the fibers from their natural polymer, reusing them in combination with our own chosen polymer

COMPOSITES - materials made of two or more materials with explicitly different physical or chemical properties that can be distinct in finished structure at micro or macroscopic scale.

FIBERS are hair-like materials that tend to stick to each other.

FILAMENTS can be twisted into yarn, thread, or rope. These can be woven to create textiles with tensile strength in two directions or knitted to create elastic textiles.

MATS are made using randomly- oriented shorter fibers. These can be needle-punched to create felted textiles.

BAST FIBER PLANTS - the same as a tree, contain cellulose fibers that are oriented to hold the stem upright.

XYLEM a brittle, woody inner core

RETTING - To make use of the fibers,

they must first be separated from the xylem (a brittle, woody inner core) by softening the natural polymers in the plant (in bast plants these are Lignin and Pectin).

CARDING when the bast fibers are separated from the woody core using rollers (breakers). The clumps are then cleaned and broken up then combed.

POLYMERS are the glue that hold the fibers together in a certain orientation.

THERMOPLASTICS can be formed into a shape, then melted and reused in a closed loop system of production. It is a polymer that turns to a liquid when heated and freezes to a very glassy state when cooled sufficiently.

PAPER is was perhaps the first biocomposite, originally made by the Egyptians from papyrus.

PLYWOOD is one of the most commonly used man-made composites. Technically, plywood is a composite made from bi-directionally oriented reinforcement fibers set in a glue resin polymer.

FIBERBOARD developed for more specialized uses or cost requirements. They are most commonly made from randomly oriented chipped or ground wood fibers set in urea formaldehyde resin polymer.

REINFORCED PLASTICS in household products are commonly made from petrochemical based plastic polymers combined with glass, carbon, or aramid fibers (man-made but not petro-chemical based)

THERMOSETS used in composites are often in the form of glue, like urea resin, polyurethane, epoxy, polyester, and vinyl-ester.

COMPOSITE TEXTILES textiles and filaments can be combined with polymers to create textiles with improved characteristics, such as tear resistance, water repellent, shape-holding, translucency, or elasticity.

RESOURCES/ books

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Tiina Härkäsalmi & Ilpo Koskinen, Multi- and interdisciplinary nature of textile design research of linseed fibres, Aalto-University, Finland

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The University of Tennessee Space Institute
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The University of Southern Mississippi Polymer Science Learning Center.
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The National organization for the Reform of Marijuana Laws
http://norml.org/index.cfm?Group_ID=3395

Invista, Common Hemp crop pests
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