BIOCOMPOSITES

Composite stand up for humanitarian causes, composites are environmentally responsible and the automation is the key for reducing the cost of manufacturing composite parts, are some of the words said before the winners of the Worldwide Competition of JEC Paris Innovation 2010 Award had heard and we totally agree.

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Overview

With thecurrent research was possible to show that certain composites applications withnatural fibers demonstrated a competitive performance comparatively to the glass fiber and consecutively a new era of biocomposites was open. The behaviour of natural fibers intrigue the researchers from all over the world. Questions on how the lotus plant can keep the water, creating a barrier without destroying the leaf, or how could be possible to save a depletion of petroleum through substitutes with bio materials makes us look for answers every day.

This report means to be the overview of the natural fibers and resins in composite materials, mostly called bio-composite. Focused on the main fibers and resins used in automotive industry, on the available manufacturing processes and finally completed with examples and suppliers. .

Bio-composites

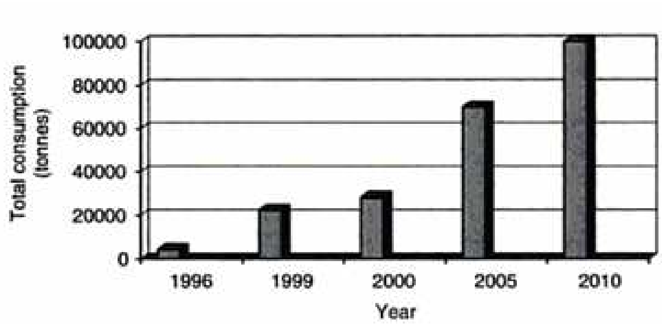
The history of natural fiber reinforced matrix started 3000 years ago when the wall houses were made using clay reinforced with straw. In the 20^{th} Century, more exactly in 1930 Henry Ford [6] had the amazing idea to investigate natural materials that shows enough strength as chicken bones. On its research laboratory was investigated a variety of natural materials, from onion to garlic, from cabbages to cornstalks, etc... In the early 1942 Henry Ford had his first prototype car made from hemp fibers, which unfortunately did not pass into a general production due to economic limitation at the time.

Since then, natural fibers continue to grow in many others industries, such as goods industry, aeronautic industry, etc...The figure below shows the replica of the deHavilland DH – 88 Comet; the original aircraft was used in the Second World War and had the fuselage made of unidirectional, unbleached flax yarn impregnated with phenolic resin and cured under pressure.

Fig 1 Replica of the deHavilland DH - 88 Comet

In the European market, the use of the natural fibers suffered depletion during 1950 to 1996, registering a significant increase for the period 2000 to 2005. The projection of the natural fiber for 2005-2010 regarding to the automotive sector could rise to between 70000t in 2005 to more than 100000t in 2010 (see Table below).

Table 1 Total consumption for natural fibers

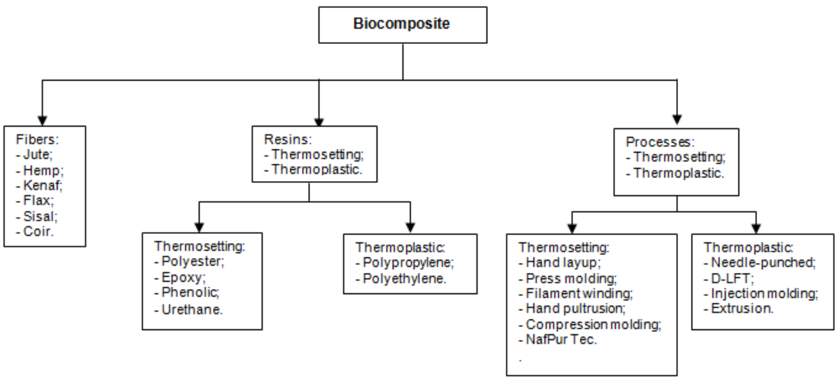


In 2010 at the JEC Composite Show, was possible to see the great European concern about the implementation of industrial bio-components, Germany had the strong presence with biocomposite final goods, since garden furniture, automotive components until pultruded profiles. Asia had showed its position in being the main supplier of raw material of natural fibers, accessories for various molding processes, and prepregs of fiberglass and carbon with epoxy. India, still maintain its monopoly on the market of the phantom veil in order to simulate the natural environment.

biocomposite (see Table 2) are composite materials compromising one or more phase(s) derived from biological origin[7].

In terms of reinforcement, bio-fibers may be classified in three main categories: straw-fibers, non-wood fibers and wood-fibers.

Table 2 Bio-composite structure



The matrix has the role to protect de fibers against the environment degradation and mechanical damage, but the main purpose is to hold the fibers together and transfer the loads on it. Generally, this matrix consists of a thermoset or thermoplastic resin, but as a demand for biocomposite, the resin should be made from renewable resources.

Chapter 1 describes a brief introduction about natural fibers and a short description of the main fibers used in automotive industry . Chapter 2 will give us an overview of the thermoset and thermoplastic resin, an introduction of the natural resin with its advantages and limitations and nevertheless a general characterization of the bio-resins. Chapter 3 specifies the main processes through the natural fibers that can be transformed in final products. Natural fibers applications and suppliers are presented in Chapter 4.

1. Fibers

Since ancient Egypt natural fibers were already being used as reinforcement materials. As we had seen above, these natural fibers are divided in three main categories: straw-fibers, non-wood fibers and wood-fibers. The non-woods fibers won the interest of industry due to the mechanical and physical properties that had showed. Inside this category, another classification depending on the plant origin is made: as bast for kenaf, flax, jute and hemp; leaf for sisal, henequen and pineapple leaf fiber; and seed for cotton; fruit coconut.

Table 3 Classification of vegetable and cellulose fiber

Bast	Leaf	Seed	Fruit	Stalk	Wood Fibers
Flax	Sisal	Cotton	Coconut	Bamboo	Hardwood
Hemp	Manila	Kapok		Wheat	Softwood
Jute	Curaua			Rice	
Kenaf	Banana			Grass	
Ramie	Palm			Barley	
Banana				Corn	
Rattan					

The application of the natural fiber composites depends on the production cost of COTS and their functional properties. Generally natural fibers cannot provide the same mechanical properties as carbon fiber, but some of them can achieve the same behavior as fiberglass. In composite materials, before being used, natural fibers are subject to preparation for operations and modification of its surface. Following the latter, the fibers should have: good adhesion between fiber and matrix; suitable degree of polymerization and crystallization; resistance to humidity and homogenous physical properties; and nonetheless should be non-inflammable.

Table 4 presents the natural fibers most industrially suitable and its mechanical properties, following the order in which they were found a resume of each type of fiber with its characterization and applications are also presented.

Table 4 Mechanical properties of selected natural fibers

Fiber	Density (g/cm^3)	Elongation (%)	Tensile Strength (MPa)	Elastic Modulus (GPa)
Jute	1,3	1,5-1,8	393-773	26,5
Hemp	1,47		690	70
Kenaf	1,45	1,6	930	53
Sisal	1,5	2,0-2,5	511-635	9,4-22
Coir	1,2	30	593	4,0-6,0

a) Jute

Jute fiber (see Fig 2) is one of the most important vegetable fiber used for various applications, being characterized by a long, soft and shiny fiber which can be spun into coarse strong threads. Environment friendly being 100% bio-degradable, the jute fiber is affordable and can be blended with other fibers, either synthetic or natural.

Jute fiber presents a high tensile strength, low extensibility, low thermal conductivity and acoustic insulating properties.

Fig 2 Jute products

A study was realized by Roe and Ansell[1] to jute – polyester composites with intent to examine the function of fiber volume fraction. The sample was made through press molding process allowing a maximum loading of 0.6 volume fraction of fiber. The results of the sample test concluded for 250 MPa tensile strength and 35 GPa for the Young´s modulus.

Another study was made of a fiber reinforced vinylester resin (reported by Ray et all[2]), with the purpose to improve the mechanical properties. The results reached after an experiment where the jute fibers were treated with 5% NaOH solution in four different time periods (2, 4, 6 and 8h) showed an improvement in the flexural strength and modulus. However, the only process that showed ability to achieve maximum loading of 35% was through the hand pultrusion technique.

The next table (Table 5) is an example from Dash, B.N., Polym. Composites, which shows the mechanical properties of jute sliver – polyester composite.

Table 5 Mechanical properties of jute sliver - polyester composites

	Unweathered		Weathered	
Properties	Untreated jute polyester	Bleached jute polyester	Untreated jute polyester	Bleached jute polyester
Ultimate stress (MPa)	132.40	117.00	88.00	78.15
Ultimate strain (%)	5.834	6.677	5.417	4.460
Tensile energy absorption (N/mm)	9.767	10.600	8.775	6.675
Tensile modulus (GPa)	2.956	2.106	3.639	3.902
Flexural yield strength (MPa)	140.4	171.8	100.7	105.76
Flexural modulus (GPa)	13.85	18.44	8.94	7.33
Inter laminar shear strength (MPa)	3.865	4.032	3.192	3.30

b) Hemp

Hemp is the name of the soft, durable fiber that is cultivated from plants of *cannabis genus* for industrial and commercial use[3]. The common application of the hemp fiber is to be blend with polypropylene in a nonwoven mat which through compression molding technique turns to a three dimensional part.

When the hemp was compared with glass fiber has showed an equivalent Young´s modulus, a much lower density and costs (approximately half the price), and a reduction in molding time.

Fig 3 Configurations of hemp fiber

Due to its properties they can be used for automotive applications, sporting goods, musical instruments, luggage, etc., through the processes available like compression molding, injection molding, and hand layup or even hybrid technologies.

Fig 4 Few examples of products made with hemp fiber

c) Kenaf

Kenaf is an herbaceous annual plant that can be grown under a wide range of weather condition, for example, it grows more than 3m within 3 months even in moderate ambient condition[4].

Fig 5 Kenaf fiber configurations

The interest in cultivate kenaf is due to its potential to absorb nitrogen and phosphorus included in the soil and also by the potential in assimilate a significant rate of carbon dioxide.

Kenaf exhibits low density, non-abrasiveness during processing, high specific mechanical properties and biodegradability. It can be used as a domestic supply of cordage fiber in manufacture of rope, twine carpet backing and burlap. In automotive industry works as a substitute for fiberglass or other synthetic fibers, and can be found in automobile dashboards, carpet padding and corrugated medium.

The main processes by which the fiber and matrix can turn into final product are injection molding and extrusion.

d) Sisal

Sisal fiber is one of the most widely used natural fibers and is very easily cultivated. Almost 4.5 million tones are produce in each year all over the world. Tanzania and Brazil are the two most important country producers.

Fig 6 Configuration of sisal fiber

Generally the sisal fibers are defined by their source, age and cellulose content, giving it the strength and stiffness. The tensile properties of the sisal fiber are not uniform along its length. The root or lower part has low tensile strength and modulus but high fracture strain. The fiber becomes stronger and stiffer at mid-span and the tip has moderate properties.

The next table (Table 6) shows the mechanical properties of the plant with different age at different temperature.

Table 6 Mechanical properties of the sisal at different ages and different temperature (compression test)

Age of plant	Toughness per unit volume (MJ/m^3)			Tensile strength (MPa)			Tensile modulus (GPa)		
	30°C	80°C	100°C	30°	80°C	100°C	30°C	80°C	100°C
3	4.8	4.9	4.1	452	350	303	26	29	21
5	5.5	7.8	4.3	508	355	300	29	–	22
7	6.0	5.2	4.7	500	300	280	34	22	17
9	7.4	5.4	5.2	581	316	339	37	17.5	21

The price of sisal fiber is situated about one-ninth of the glass fiber. For specific price (modulus per unit cost) it is very close to the jute amongst all the synthetic and cellulosic fibers.

e) Coir

Coir fiber is geometrical found between the hard internal shell and the outer coat of a coconut. The fiber is pale when immature, but latter become hardened and yellowed as a layer of lignin. The coir fiber exists in two types: brown coir and white coir. Brown coir is harvested from fully ripened coconuts, it is thick, strong and has high abrasion resistance. Generally it is used in mats, breeches and sacking. Mature brown coir contains more lignin and less cellulose than fibers such as flax and cotton, and thus make then stronger but less flexible.

White coir fibers are harvested from the coconuts before they are ripe. This fibers are white or light brown color, are smoother and finer and usually weaker than brown coir.

Fig 7 Various configuration of the coir fiber

2. Resins

Since early times, resin has been a key ingredient to varnish materials for decorative and protective purposes. Resin is a hydrocarbon secretion of many plants, particularly coniferous trees. During decades, many functions of the resin were discovered, from incenses to perfume, from adhesive to varnish, etc.

Fig 8 Images from tree resin

Several derivations of natural resins were made; being the most used the synthetic resins from thermoset and thermoplastic groups. The next tables (7 and 8) present the polymers behavior with origin groups from thermoset[5] (Table 7) and thermoplastic[5] (Table8).

Table 7 Properties of typical thermoset polymers for natural fiber composites

Property	Polyester	Vinylester	Epoxy
Density	1,2-1,5	1,2-1,4	1,1-1,4
Elastic Modulus (GPa)	2-4,5	3,1-3,8	3-6
Tensile Strength (MPa)	40-90	69-83	35-100
Compressive Strength (MPa)	90-250	100	100-200
Elongation (%)	2	4-7	1-6
Cure shrinkage (%)	4-8	-	1-2
Water absorption (24h@20^{o}C)	0,1-0,3	0,1	0,1-0,4
Izod Impact, Notched (J/cm)	0,15-3,2	2,5	0,3

Table 8 Properties of typical thermoplastic polymers used in natural fiber composite

Property	**PP**	**LDPE**	**HDPE**	**PS**	**Nylon 6**	**Nylon 6,6**
Density (g/cm^3)	0,899-0,920	0,910-0,925	0,94-0,96	1,04-1,06	1,12-1,14	1,13-1,15
Water absorption (24h@20ºC)	0,01-0,02	<0,015	0,01-0,2	0,03-0,10	1,3-1,8	1,0-1,6
T_g (ºC)	-10 to -23	-125	-133 to -100	-	48	80
T_m (ºC)	160-176	105-116	120-140	110-135	215	250-269
Heat Deflection Temp (ºC)	50-63	32-50	43-60	Max.220	56-80	75-90
Coefficient of thermal expansion (mm/mm/ºC*10^5)	6,8-13,5	10	12-13	6-8	8-8.6	7,2-9
Tensile strength (MPa)	26-41,4	40-78	14,5-38	25-69	43-79	12,4-94
Elastic modulus (GPa)	0,95-1,77	0,055-0,38	0,4-1,5	4-5	2.9	2,5-3,9
Elongation (%)	15-700	90-800	2,0-130	1-2,5	20-150	35->300
Izod impact strength	21,4-267	>854	26,7-1,068	1,1	42,7-160	16-654

* PP= polypropylene; LDPE= low density polyethylene; HDPE= high density polyethylene.

With the depletion of the petroleum and the constant concern for the environment has been opened a new era for bio-resin named as green resins.

Knowing that natural resins are water resistant and soluble in organic solvents, ether or chloroform, they unfortunately cannot be use for the purpose of the project in case. The bioresin offer an interesting potential for use in various application, even if the contribution of plant-based thermoset continue to be very low.

The lines below speak about the natural resin and bio-resin.

a) Natural resin

Natural resin is a resin product which comes from a plant (consisting of amorphous mixture of carboxylic acids, essential oils and isoprene – based hydrocarbons) in contrast with synthetic resin.

Fig 9 Various configurations of the natural resins

The natural resins are divided as follow:

- Resins, are resinous products obtained from the pitch of pine trees. Rosins are used in varnishes, adhesives and various compounds;
- Oleoresins, are natural resin containing essential oils of plants;
- Gum resins, are natural mixtures of true gums and resins including natural rubber, gutta percha, gamboges, myrrh, and olibanum (spicy balsamic resins);
- Fossil resins are natural resins from ancient trees that have been chemically altered by long exposure. Amber and copal are examples of this type of resin.

b) Bio-resin

Bio-resin is a resin system based on vegetal oil and/or other natural ingredients. The hardener, (the integral part of the resin system), generally contains blocked isocyanate, with the intention to achieve its role and in the same time preventing the escape of the potential harmful substance. In this way bio-resin offers a work environment toxicologically free being kindly with the atmosphere.

With the main advantages that these bio-resins are suitable for all major fibers and are compatible with polyesters and epoxy substrate, presents the major characteristics the free odor and shrinkage, the free toxic fumes without being flammable.

Incorporating renewable sources as raw materials to replace synthetic petroleum based polymers; the following table presents the general characteristics of the bioresins.

Table 9 General characteristics of Bioresins

Characteristics	Bioresin Basic Formulation

Gel time 25ºC	30 - 40 min
Mixture viscosity 25ºC	750 cps
Mix ratio by volume (resin/prepolymer)	1:0.5
Density (20ºC)	1,1 g/cm
Water absorption %	< 1%
Hardness	90 Shore A
Shelf life (months)	12

Depending on its viscosity and thixotropic characteristics, the bio-resins can be use for hand layup, autoclave, resin transfer molding and spray systems.

The bio-resin can be found in industry application for alternative energy, pump shafts for machine in food industry, in construction and transportation.

3. Processes

As in composite product with synthetic fibers, the drivers for the selection of the appropriate process technology are the same with the natural fibers. Issues like the final product shape, performance, cost of the product and low cost of manufacture involves, too the natural fibers. Several factors which must be considered in selecting the process are the distribution of the resin within the fibers; the compatibility between the hydrophobic matrix and hydrophilic fibers; that fiber attrition is minimized due to processing to ensure reinforcement; that the moisture inherent within the fiber is at the desired level.

These factors were included in the processes presented above as for thermoset process, regarding to the thermoplastic processes extrusion, injection and D-LFT are descript. As rule, the same processes as for synthetic fibers involves the natural fibers, with some changes including the dry process of the natural fiber prior to impregnation,

3.1. Thermoset

a) Hand layup

The method involves the same behavior as for any other composite synthetic reinforcement. Beginning in preparing the mold, applying an enough degree of finishes and release agent. Then a gel coat consisting of a resin with or without a pigment is applied to the same mold to guaranty a resin-rich top surface. The prepreg is laid on the prepared mold, than is pressed with a hand roller to eliminate the air bubbles and the excess of resin. After curing the product is subjected to a post - curing treatment.

Through this process the level in achieving a fiber loading is not high, being dependent on the post – cure treatment and on the anatomical features of the natural fibers. It is mandatory for the natural fiber reinforcement to be dry in an oven prior to resin impregnation, to avoid poor wetting and moisture entrapment in the composite.

The natural fibers that may be used through this process with resin polyester are: coir fiber, banana/sisal, banana cotton fabric.

b) Press molding

Press molding process includes sheets molding, bulk molding and cold press and hot press techniques. The method is similar to hand layup technique, with the exception that makes use of a matched dies which are closed before cure takes place by the application of pressure. The cure temperature is between 40 to 50ºC for cold press and 80 to 100ºC for hot press. The technique achieved good results incorporating fiber such us: coir, sisal, banana, pineapple, and jute and banana cotton fabric in the polyester resin.

Via press molding a much larger volume of fiber loading was achieved comparing with hand layup process. The explanation is that the applied pressure which compresses the intrafiber voids or lumens are made in a more efficient way and allows a greater amount of fiber incorporation.

c) Filament winding

In filament winding the continuous fibers are impregnated in a resin mix bath and then wound on a rotating mandrel. The successful cylinders with longitudinal or helical and hoop reinforcement were made with sisal-epoxy and jute-polyester.

d) Hand pultrusion

As is known, pultrusion is a useful technique in making continuous products for varied application. Reported by *Ray et al*, they used this method to fabricate composite rod samples for experimentation. The hollow glass tubes were used as mold. The predried fiber were mixed with the resin system (resin mix with accelerator, catalyst and promoter) and pulled through the glass tubes by hand to produce composites in the form of rods.

Generally used for manufacturing synthetic fiber reinforced composites, remains an enormous scope in utilizing this method for manufacturing biocomposite for widespread applications.

e) NafPur Tec.

NafPur Tec process consists in a sprayable polyurethane resin and nonwoven flax/sisal fiber. The following figure (Fig 10) shows the manufacturing step process where mat predried fibers (1) are sprayed on each side (2) than stacked in a charge pattern before being place into the mold (heated press).

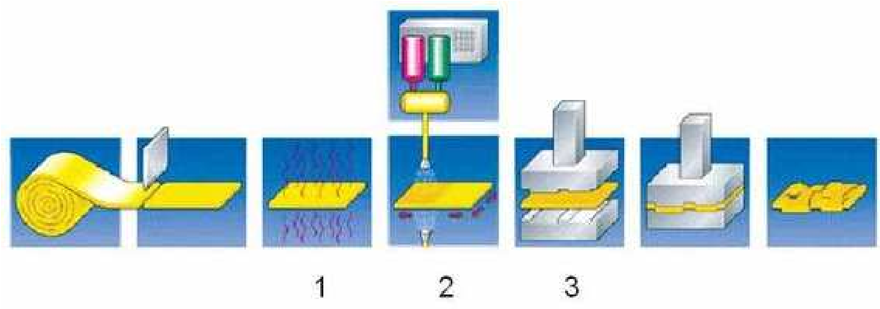


Fig 10 NafPur Tec

The prepreg has a room temperature outlife of 30 to 45 minutes with molding curing around 130ºC in 60 seconds per cycle. The figure below shows various products made through NafPur Tec process.

Fig 11 Various products made by NafPur Tec method

3.2. *Thermoplastic*

a) Extrusion and injection molding

- **Extrusion**

Extrusion is the process where a solid plastic, usually in the form of beads or pallets, is continuously fed to a heated chamber and carried along by a feed-screw within. As the solid resin is conveyed, it compressed, melted and forced out of the chamber through a die. Through the cooling process the melt part results in a resolidification of the resin into a piece.

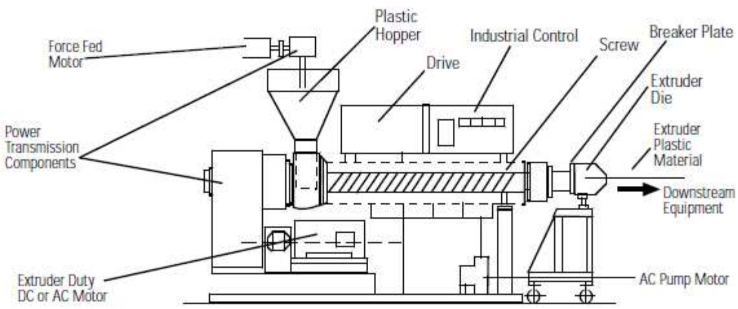


Fig 12 Extruder equipment

In the case of bio-composites, the basic extruder equipment (see Fig 12) works the same or had supported few modifications. Generally, the bead or pallets of the thermoplastic resin are mixed together with 30 to 40% of short/long natural fibers, compressed, melted (wherein the natural fibers are impregnated with resin) and forced out through a die. After cooling process the melt part results in a continuous profile.

The equipment which had supported modifications is intended to create raw materials for the injector. The adaptations were made to the feed stocker; in fact another feed stocker was added, being in this way guaranteed the exactly quantities of fibers inside of beads or pallets.

Fig 13 Extruded natural fiber and thermoplastic resin beads

Other types of extruders can include twin screws, which can be co-rotating and counter rotating and planetary extruders which can include single-screw. All this adaptations had and achieve the same goals: material feed, heat application, dispersing mixing, distribute mixing, devolatilization and material extrusion through die.

- **Injection molding**

Injection molding is the main process used by manufactures for making composite products, where complex shapes are needed in a cyclic, high volume production. The advantages on using this process are the excellent dimensional tolerance and short cycle times, coupled with few post processing operations.

According to the JOM – November 2006 magazine, one of the challenges posed by injection molding natural fibers composites is to produce pellets of a consistent quality. This challenge has been exposed by the North American and European injection molding equipment suppliers through a process called direct long fiber thermoplastic molding D-LFT and is descript on the following sentences.

b) D-LFT

Direct Long Fiber Injection or D-LFT process consist in a twin –screw extruder where raw polypropylene and glass reinforcements are melt resulting in a molten charge, that is subsequently compression molded in a cold tool.

Composite Products Inc. adopted this process to produce polypropylene reinforced with 40% natural fiber, such as: kenaf, flax and natural fiber/glass hybrids. Another company is Daimler Chrysler AG, which introduced the first large scale application of natural fiber products (two-door vehicle of the 2005 Mercedes A-Class) resulting from D-LFT process.

4. Applications and suppliers

The requirements of light weight, low cost and nevertheless the reduction of the CO_2 turn the manufactures of all the industry to pay more attention of the renewable raw materials. The utilization of the natural fibers offers the potential to replace a large segment of the glass fiber and mineral fillers at a much lower cost. Door panels, seat backs, headliners, package trays, dashboards and pultruded tubes are made by natural fibers reinforced thermoset or thermoplastic resin (see Fig 14).

Fig 14 Examples of natural fiber composite parts

The following tables present some of suppliers of natural fiber, natural resin, bio-resin, synthetic resin, bio-thermoplastics, etc. (Table 10) and informative price (Table 11) for some natural fibers found in our pursuit.

Table 10 Various suppliers of Biocomposite

Supplier	Type of product	Phone/Country	E-mail	SITE
Quadrant Plastic Composites	**Natural fibers**	**(+41) 62 885 81 50 / Switzerland**	qpc@qplas.com	www.quadrantcomposites.com
Manila Cordage Co	**Natural fibers**		-	www.manilacordage.com
PLT	**Natural resin**	**India**	-	www.plthomas.com
Eco-TEK	**Bio resin**	**(+44) 1473 288997**	europe@aoc-resins.com	www.green-resins.com
Bioresin	**Bio-resin**	**(+55) 11 3611 3659 / Brasil**	evieytes@bioresin.com.au	www.bioresin.com.au
CARGIL Ltd	**Sealant, adhesive**		customerservice_polyols@cargill.com	www.bioh.com
Composite Products Inc	**Polypropylene reinforced with 40% of kenaf, flax and fiberglass**	**(1) 507-452-2881 / USA**	sales@compositeproducts.com	www.compositeproducts.com
KERAX Ltd	**Bio - Wax, wax blended**	**(+440) 1257 237 350 / England**	-	www.kerawax.com

FlexForm TECHNOLOGIES	**Non-woven composite material made from a blend of natural fibers and polypropylene**	**5742953777 /**	**info@flexformtech.com**	**www.flexformtech.com**
PURAC	**Bioplastics, green chemicals**	**(+34) 93 568 6300 / Spain**	-	**www.purac.com**
NOVAMONT	**Biopolymers**	**(+39) 0321699611 / Italy**	-	**www.materbi.com**
FKuR Kunststoff GmbH	**Natural fiber reinforced plastic; Biodegradable plastic for injection/extrusion**	**(+49) 21 54 92 510 / Germany**	**info@fkur.com**	**www.fkur.com**
Matexplas	**Thermoset resins**	**(+351) 219407290 / Portugal**	**geral@matexplas.pt**	**www.matexplas.pt**
Rebelco	**Thermoset resins**	**(+351) 21 456 63 35**	**filipecorreia@rebelco.pt**	**www.rebelco.pt**
Poolkemie	**Thermoset & Thermoplastic resins**	**(+39) 0113473370 / Italy**	**info@poolkemie.it**	**www.poolkemie.it**
MAPRIL SA	**Thermoplastic resins**	**(+351) 220 304 300 / Portugal**	**mapril@mapril.com**	**www.mapril.com**
Zeus Quimica, Lda.	**Thermoset & Thermoplastic resins**	**(+351) 229 397 360 / Portugal**	**zeus@zeusquimica.pt**	**www.zeusquimica.pt**
TECNARO GmbH	**Thermoplastics from renewable resources**	**(+49) 70 62 91 78 902 / Germany**	**info@TECNARO.de**	**www.tecnaro.de**
				http://www.omniglass.com/fiberglassdoor.asp
				http://www.hiendl-kunststofftechnik.de/services/kunststoff-artikel/?n=20-155

Table 11 Price of the natural fibers compared to glass

	Glass	Jute	Hemp	Sisal	Coir
Price of raw fiber [€/kg]	1,3	0,35	0,6-1,8	0,6-0,7	0,25-0,5

Conclusion

Motivated by the economic crises, the depletion of the petroleum and nevertheless the environment concerns, the biocomposites had gain during time crucial importance.

Fibers like jute, hemp, kenaf, sisal, coir, etc., are some of the fibers which are not only raw materials of biocomposite, but are also the need of the environment (absorption of CO_2 – see Chapter 1) and the economic potential of the countries under development. As raw materials fibers like hemp and flax can compete without any barriers with the tensile strength, elongation at the failure and elasticity of the E-glass fiber. From the cost view, the natural fibers had gained in front of fiberglass its own place without any difficulty, due to its low price.

The matrix is still the current problem of biocomposites, because if is it natural is soluble in organic solvents and if is it bio – thermoset is difficult to impregnate the fibers. In the case of bio-thermoplastics, these resins present limitations in terms of mass production due to demand vs. supply on the market.

About the processes fabrication, as rule, the same processes as for synthetic fibers involve the natural fibers, with some changes including the dry process of the natural fiber prior to impregnation.

Many studies regarding biocomposites are in development, subjects like: fiber architecture, (fiber geometry, orientation, and volume friction); fiber impregnation; fiber-matrix compatibility; maximum quantity of the fiber in the resin system, the optimum quantity of the fiber to achieve the desired product (mechanical properties), etc...

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