POLITECNICO DI TORINO

Department of Mechanical, Aerospace, Automotive and Production Engineering

Bachelor of Science in Mechanical Engineering

Bachelor's Degree Thesis

The mechanical properties of natural fiber and a case study of Coconut fibers

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Content

1. Introduction

In modern day the persistent for the plastics is growing higher and higher. The landfill space, which is used to dump plastics and petroleum products need to produce the plastics are rapidly ending. Due to the above reasons, a vacuum for an alternative materials is formed. A cheaper and sustainable composite is one of the solutions that many researchers are researching. Composites made of fibers such as Flax, Sisal, Hemp are already big competitors in the game and currently there are many possibilities to check out.

Present-day natural fibers are used from the automotive industry, sporting goods to the electronics industry. In 2016 it was recorded that market value for the Natural fiber composites (NFC) had reached 4.46 billion US dollars [1]. And the amount of NFC used by sector is shown in figure 1. Industries such as automotive hugely use the composites with wood due to its low-density properties.

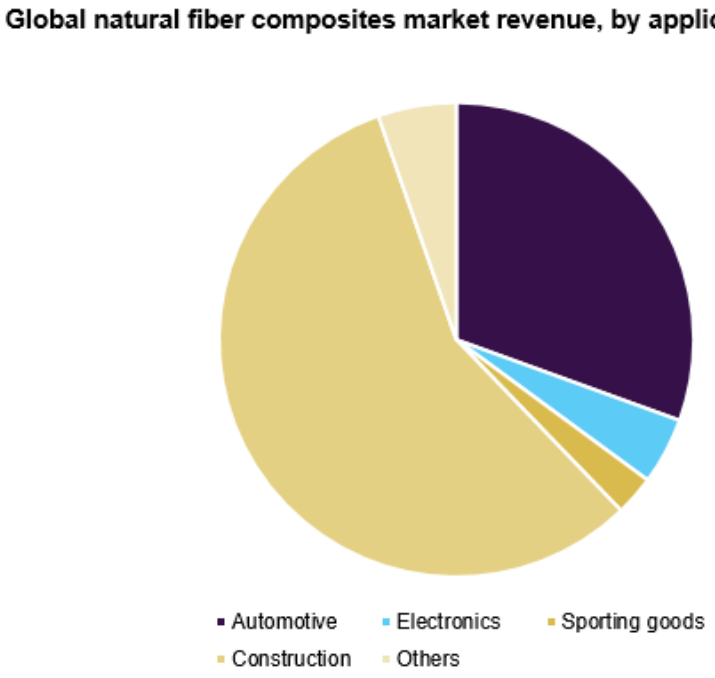


Figure 1 [1].

As the natural fibers are light compared to the synthetic fibers the strength to density ratio is better in the natural fiber and the energy consumed by the NFC in manufacturing is lower than the synthetic glass fiber composites. The emission of the toxic waste in manufacturing the NFC is almost zero and the hazards in manufacturing are very low which mean the risk that employee get exposed is lower. But still, there are quite a lot of the challenges that NFC

needs to overcome a few of those challenges are the reaction for the moisture, weak bond for the matrix, low durability and low strength compared to the synthetic fiber composites.

1.1 The snowboard

In the modern world, sporting equipment's are made with different kind of materials. For example, the snowboard is made of glass fiber, wood, and other plastic composites. Earlier days, most of the sporting equipment were made out of the wood with the industrial evolution plastic and composites snowboards were introduced to the markets. But these materials used increases the carbon footprint to the world which the modern geology and the biology face devastating effects.

Now the world has again started to move toward sustainable products. And this trend has even affected the sporting industry. Snowboard is no exception for this trend. Currently there are many companies who has been there and trying to achieve this goal. For example, Bcomp company has tried to achieve this goal by using the basil fibers. The figure 2 show an example for snow board with natural materials.

Figure 2 [2].

R.G. glide team is a student team established in the Politecnico di Torino in the aim of making a sustainable snowboard. This thesis was done as an approach to find a suitable fiber for above purpose. There were many fibers used in the industry. But an unconventional approach was taken to test the coconut fibers especially leaf sheath, whether it is suitable to fabricate a snowboard.

2. Natural fibers

Fibers are a class of hair-like material that are continuous filaments or are in discrete elongated pieces, similar to pieces of thread. They can be spun into filaments, thread, or rope. They can be used as a component of composites materials. Fibers can also be matted into sheets to make products such as paper. Based on the type on the resin used in making the composite one can categories the composites and natural composites or partial composites. Mainly natural fibers can be divided into three main categories.

- Plant fibers

  The plant fiber mainly made of the cellulose, hemicellulose, lignin, pectin and other waxy substances. There are two general classifications of plant fibers. They are Primary and secondary [3]. Primary are the plants that are cultivated in the intention of harvesting the fibers. Few examples are Jute, Kenaf, Hemp. The secondary is the by-product of any other product such as pineapple, oil palm, stalks. Figure 3 shows some flax fibers under the dew retting process.

Figure 3 [4].

- Animal fibers

  Animal fiber is the second most used fiber after the plant fibers. These fibers mainly constituted by proteins. Animal fibers are widely used in the textile industry than the manufacturing of the composites.

Figure 4 [5].

- Mineral fibers

  Mineral fibers are naturally occurring fiber or slightly modified fiber procured from minerals. Asbestos is the only naturally occurring mineral fiber. Russia is the biggest producer of the asbestos so far. There are varies health issues reported regarding the asbestos composites

Figure 5 [6].

Mainly in this thesis, I discuss the plant fiber as it is widely used and generally higher stiffness than the other kind of fibers (an exception for above statement is silk [7]).

2.1 Plant fiber

In human civilizations, the earliest use of the plant fibers dates back to 36000 BP from Georgia [8]. Before the industrial revolution, the fibers were mainly used in the textile industry. Today the fibers are used in different industries. The rags for the textile were mainly made from hemp, linen, and cotton. In 1843 that paper production was introduced which is a product out of the short fibers from the trees [9]. Currently, the top four most used fibers are cotton, flax, jute, sisal. And the countries which produce the highest Jute fibers are India, Bangladesh, PRC. The USA is the highest cotton producing country while Canada is the highest Flax fibers producing country in the world [10].

There are different methods for this process based on the type of fiber. For example, Bast fibers are harvested through retting which is where microbes are utilized to remove soft tissues from the plant and only the useful fibrous material remains. Decortication is a method used to harvest the hard(leaf) fiber, in this process a machine or hands are used for the extraction. The Surface fibers such as cotton are harvested through ginning. In ginning process, machine removes the fibers from other plant material [9]. The plant fibers can be categorised as shown in figure:

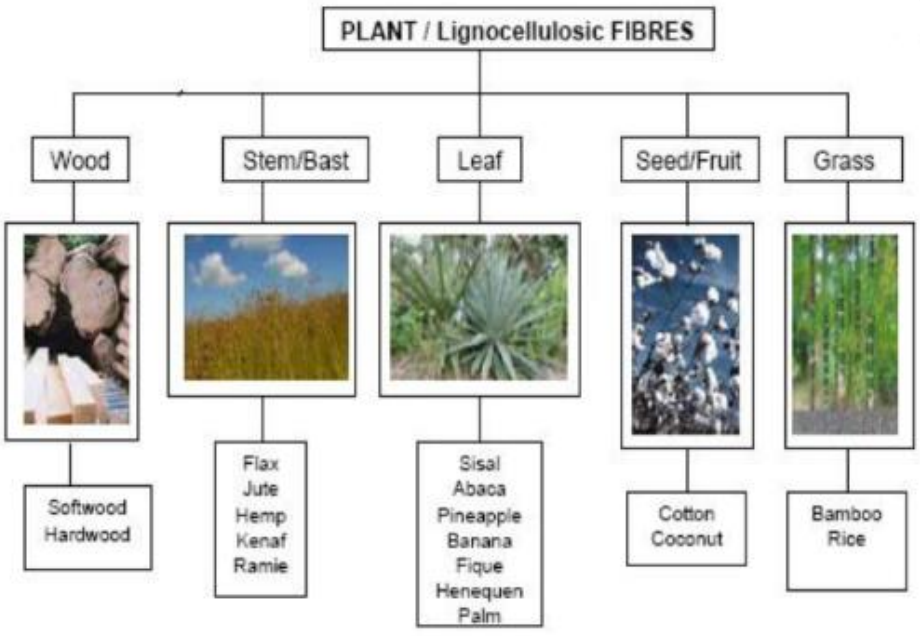


Figure 6 [11].

2.1.1 Microscopic Structure.

2.1.2.1 Introduction

Natural fibers are mainly derived from the plants consist of cellulose, hemicellulose, lignin, pectin, waxy substances. The quantity of the substance present in the fiber change between different fibers. This is one of the reasons for the variation of mechanical properties between each different kind of fibers. The stiffness of the fiber is derived from the cellulose in the form of fibrous molecular bundles known as microfibrils arranged in lamellae in the plant cell wall around a hollow core (lumen) [12]. Other constituents such as hemicellulose, lignin, pectin, wax bind to stiff microfibrils and act as the matrix phase in a cellular biological composite [12]. A general diagram of the above substances in structure is shown in Figure 7.

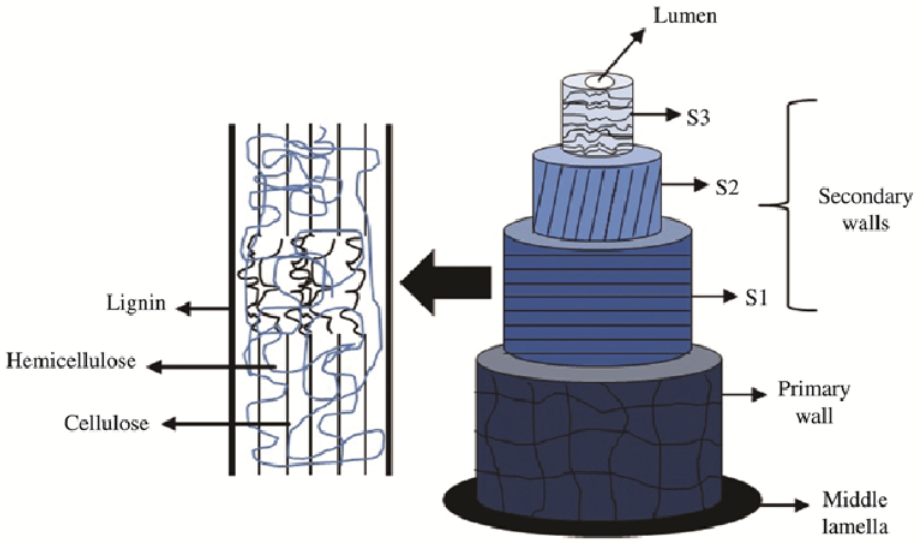


Figure 7 [13].

2.1.1.2 Cellulose

Cellulose is the major constituent of the plant fibers. It also demonstrated by table 1. The amount of the cellulose present in the fibers vary depend on the method of analysis, the growth environment and geographical location of the plant, the level of maturity at the point of harvest and the position in the plant [12]. Cellulose is a highly crystalline structure which contains as much as 80% of crystalline regions [14]. Generally, with the increasing cellulose

content of the fibers, the tensile strength and Young's modulus of plant fibers increase [14]. Researchers have found that hydrogen bonds present in between the celluloses are the most prominent bonds observed. Figure 8 shows the molecular structure of the cellulose.

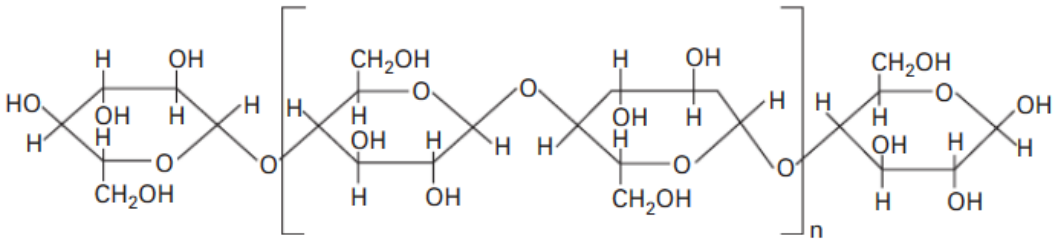


Figure 8 [12].

Normally the diameter of cellulose fibrils is about 9–20 nm [12], which are made up of cellulose molecules in an extended chain formation and provide mechanical strength to the fiber [12]. The strength of the fiber depends on the orientation of the fibrils in the fiber. As shown in figure 9, the S2 influence for the strength of the fiber as the thickness of the layer is very high.

Some researchers have given the relation for the axial young modules by associating the wrapping angle of fibrils in the thickest layer in the fiber. The axial young modules of the fibrils are given by equation 1. In figure 9, the S2 layer is chosen and the angle is measured to the axial direction of fiber as shown in figure 9.

$$E_C = E_F \cos^2\theta \quad 2.1$$

Equation 1 [12].

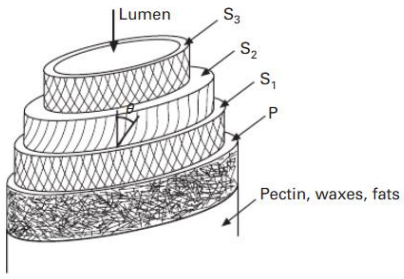


Figure 9 [12].

Figure 10 shown the young modules of some fiber how that the young's modules vary and depend on the Microfibrils angle for different kind of the fibers. Flax fibers and the Pineapple

fibers have the lowest Microfibril angle resulting in the highest young's modules. Coir and the cotton have the lowest Microfibril angle resulting in the lowest Youngs modules.

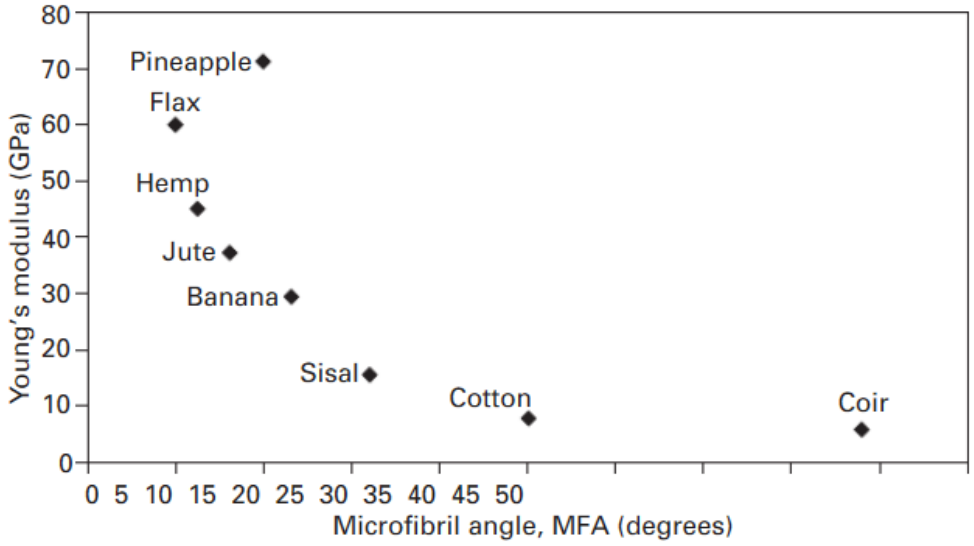


Figure 10 [12]

2.1.1.3 Hemicellulose, Lignin, Pectin

Hemicellulose is made up of highly branched or linear polysaccharides. It is more amorphous as many side groups attach to the heteropolysaccharide structure [12]. Figure 11 represents the molecular structure of the hemicellulose. It is the second largest constituent in the fiber. It is more closely associated with the lignin. Lignin and the hemicellulose sum up to 30%-40% of the dry weight of the plant cell [12]. Hemicelluloses is high water absorbing substances. Therefore, the fiber shows water absorbing properties which is one of the potential problems that is addressed later. when the amount of the hemicelluloses increases, the tensile strength increases because hemicelluloses are amorphous in nature. And it can result in nonhomogeneous in their properties. By the treatment done on the fiber the hemicellulose present in the fibers is removed.

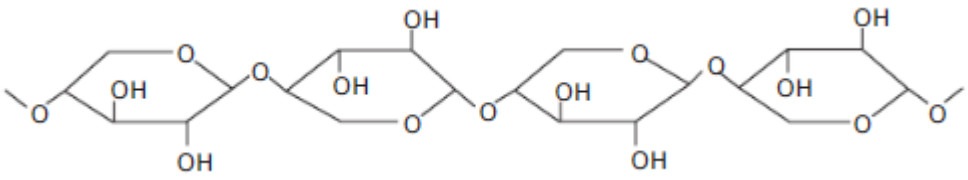


Figure 11 [12].

Lignin is amorphous, stiffens the cell walls, and acts as a protective barrier for the cellulose [15]. Both the lignin and the hemicellulose act as a cementing phase for the cellulose. Figure 12 shows the molecular structure of the lignin.

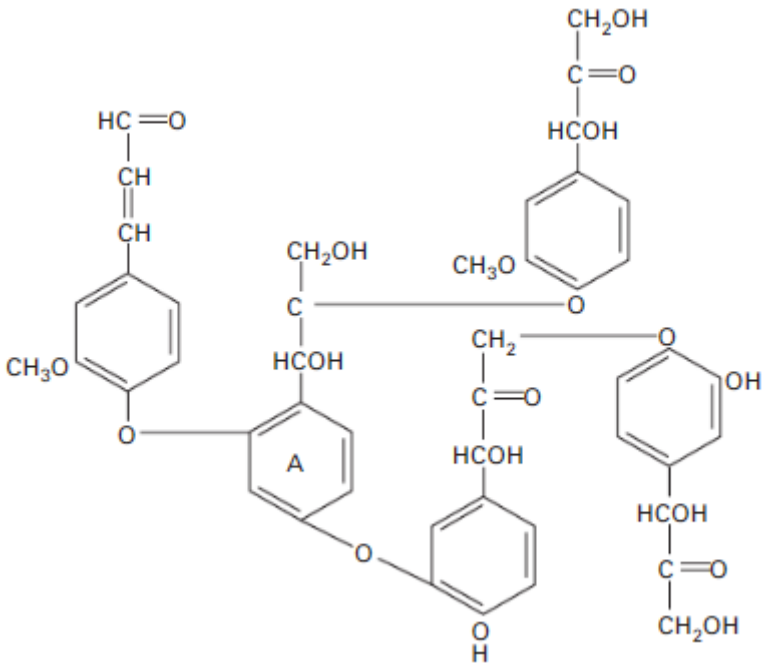


Figure 12 [12].

Pectin occurs in plant cell with the lignin and hemicellulose [12]. Pectin's is mainly concentrated in the middle lamellar and the primary wall. The removal of pectin's within fiber bundles such as those derived from flax and hemp is responsible for separating the bundles into ultimate fibers [12]. Pectin's have long and curved with worm-like positions and Hairy regions are even more convoluted. They are commercially important because of their ability to form gels, for example in fruit preserves.[122]

The ductility of the fiber increase when there is a spiral type of fibril aligned along the fiber axis. If the fibrils are rigidly aligned along the fiber axis the fibers has higher tensile strength and not flexible.

Fibre	Cellulose(wt%)	Hemicellulose(wt%)	Lignin (wt%)	Waxes(wt%)
Bagasse	55.2	16.8	25.3	–
Bamboo	26–43	30	21–31	–
Flax	71	18.6–20.6	2.2	1.5
Kenaf	72	20.3	9	–
Jute	61–71	14–20	12–13	0.5
Hemp	68	15	10	0.8
Ramie	68.6–76.2	13–16	0.6–0.7	0.3
Abaca	56–63	20–25	7–9	3
Sisal	65	12	9.9	2
Coir 3	2–43	0.15–0.25	40–45	–
Oil palm	65	–	29	–
Pineapple	81	–	12.7	–
Curaua	73.6	9.9	7.5	–
Wheat straw	38–45	15–31	12–20	–
Rice husk	35–45	19–25	20	14–17
Rice straw	41–57	33	8–19	8–28

Table 1 [12].

2.1.2 Mechanical Properties

2.1.2.1 Introduction

The plant fibers show good results in term of stiffness and tensile strength but those values are lower than the values of E glass fiber which is synthetic. The advantage for the plant fibers over the synthetic fibers is that the density of the generally the plant fiber is lower than the synthetic fiber. There the ratio of strength to density is better in the natural fibers. Table 2 shows some properties of some natural fibers including the E-glass fibers.

Fibre	Density (g/cm^3)	Length (mm)	Failure strain (%)	Tensile strength (MPa)	Stiffness/Young's modulus (GPa)	Specific tensile strength ($MPa/g\ cm^{-3}$)	Specific Young's modulus ($GPa/g\ cm^{-3}$)
Ramie	1.5	900–1200	2.0–3.8	400–938	44–128	270–620	29–85
Flax	1.5	5–900	1.2–3.2	345–1830	27–80	230–1220	18–53
Hemp	1.5	5–55	1.6	550–1110	58–70	370–740	39–47
Jute	1.3–1.5	1.5–120	1.5–1.8	393–800	10–55	300–610	7.1–39
Harakeke	1.3	4–5	4.2–5.8	440–990	14–33	338–761	11–25
Sisal	1.3–1.5	900	2.0–2.5	507–855	9.4–28	362–610	6.7–20
Alfa	1.4	350	1.5–2.4	188–308	18–25	134–220	13–18
Cotton	1.5–1.6	10–60	3.0–10	287–800	5.5–13	190–530	3.7–8.4
Coir	1.2	20–150	15–30	131–220	4–6	110–180	3.3–5
Silk-	1.3	Continuous	15–60	100–1500	5–25	100–1500	4–20
Feather	0.9	10–30	6.9	100–203	3–10	112–226	3.3–11
Wool	1.3	38–152	13.2–35	50–315	2.3–5	38–242	1.8–3.8
E-glass	2.5	Continuous	2.5	2000–3000	70	800–1400	29

Table 2 [3].

Alignment of the fiber in the matrix is a major factor which influences the properties of the composites. Researchers have found that highest strength is achieved at approximately 73 m% fiber for aligned fiber composites, a higher fiber content than that from which the best strengths can be achieved with more randomly aligned/shorter fiber composites, presumably due to the higher compaction limit with more aligned fiber. Table 3 gives some properties of the composites for different fibers and matrixes.

Although Table 2 shows that the sisal fibers have the highest tensile strength one would expect to have the highest tensile strength in composites. But by table 3 it is clear that the Flax fibers have come close to the sisal fibers with a better matrix. Therefore, the table 2 does not represent the full spectrum of possibilities of the natural fibers.

The reinforcing elements of natural fibers are cellulose microfibrils; the microfibrils are surrounded by the matrix elements hemicelluloses and lignin. When a load is applied, the microfibrils become aligned with the fiber axis. The failure of fiber takes place when a matrix element loss it is bonding with the reinforcing fibrils, and the hydrogen bonding in the cellulose microfibrils is broken. Hence, the smaller the content of cellulose, the lower the tensile strength[b]. The natural fiber with lower stiffness can be used for non-structural purposes.

Fibre	Matrix	Fibre content (m%)	Tensile strength (MPa)	Stiffness/Young's modulus (GPa)	Flexural strength (MPa)	Flexural modulus (GPa)	Charpy (c) or Izod (i) impact strength (kJ/m^2 or J/m)	Notes: Processing/length/ treatment
Sisal (aligned)	Epoxy	~73	410	6	320	27		Alkali treated bundles CM/leaky mould
Sisal (aligned)	Epoxy	~77	330	10	290	22		Untreated bundles CM/leaky mould
Flax (aligned)	Epoxy	46/54	280/279	35/39				Enzyme extracted RTM
Harakeke (aligned)	Epoxy	50/55	223	17	223	14		CM
Harakeke (aligned)	Epoxy	52	211	15				CM
Sisal (aligned)	Epoxy	48	211	20				RTM
Sisal (aligned)	Epoxy	37	183	15				RTM
Flax (yarn) (aligned)	Epoxy	45			311	25		Not stated
Hemp (aligned)	Epoxy	65	165	17	180	9	15 (c)	CM
Flax yarn (aligned)	Epoxy	~31	160	15	190	15		Hand lay-up (knitted yarn)
Flax yarn (aligned)	Epoxy	45	133	28	218	18		Autoclave
Flax (aligned)	Epoxy	37	132	15				RTM
Flax hackled (aligned)	Epoxy	~28			182	20		Pultruded
Flax yarn (aligned)	VE	~24	248	24				RTM
Flax (sliver) (aligned)	UP	~58	304	30				Soxhlet extracted Vacuum impregnated/CM
Flax yarn (aligned)	UP	~34	143	14	198	17		RTM (knitted yarn)
Alfa (aligned)	UP	48	149	12				Alkali treated then bleached
Flax yarn (aligned)	PP	72	321	29				Filament wound
Flax yarn (aligned)	PP	30	89/70	7/6			88/115 (c)	Pultruded flax/PP yarn
Flax (aligned)	PP	50	40	7			751 (i)	Needle punched flax/PP mats CM
Flax (aligned)	PP	39			212	23		Dew retted, boiled, MAA-PP coupled
Flax sliver (aligned)	PP	44			146	15		Wrap spun flax sliver/PP hybrid yarn, CM
Hemp (aligned)	PP	46			127	11		Wrap spun, short hemp/PP hybrid yarn, CM
Kenaf selected (aligned)	PLA	~80	223	23	254	22		Emulsion PLA Prepreg CM
Hemp (carded)	PLA	30	83	11	143	7	9 (c)	Alkali treated CM
Kenaf (aligned)	PLA	40	82	8	126	7	14 (c)	CM
Hemp (aligned)	PLA	30	77	10	101	7	19 (c)	Wrap spun alkali treated short hemp hybrid yarn, CM
Kenaf (aligned)	PHB	40	70	6	101	7	10 (c)	CM
Flax sliver biaxial/major axis	Epoxy	~46	200	17	194	13		Wrap spun sliver, woven, weft:warp strength 10:1
Flax (woven)	Epoxy	~50	104	10				Sized and dried prior to pre-preg
Flax yarn (woven)	VE	~35	111	10	128	10		RTM
Jute (woven)	UP	35	50	8	103	7	11 (c)	RTM
Hemp (biaxial)	PLA	45	62	7	124	9	25 (c)	Wrap spun bleached hemp hybrid yarn, CM
Harakeke (DSF)	Epoxy	45	136	11	155	10	10 (c)	Alkali treated CM
Hemp (DSF)	Epoxy	50	105	9	126	8		Alkali treated CM
Hemp (DSF)	Epoxy	65	113	18	145	10	11 (c)	CM
Harakeke (DSF)	PLA	30	102	8				Alkali treated CM
Hemp (DSF)	PLA	25	87	9				Alkali treated CM

Table 3 [3].

Flax (short-non woven)	Shellac	~49	109	10				
Harakeke (random)	Epoxy	45			188	9		Alkali treated Vacuum bagged CM
Flax (random)	UP	39	61	6	91	5	13 (c)	RTM
PALF (random)	UP	30	53	2	80	3	24 (c)	CM
Wood BKP	PP	40	50	3	78	3	40 (i)	MAPP coupled IM
Flax	PP	30			74[b]		22[c] (c)	MAPP coupled IM
Jute	PP	60	74	11	112	12	195 (i)	MAPP coupled IM
Newsprint	PP	40	53	3	94	4	200 (i)	MAPP coupled IM
Kraft	PP	40	52	3	90	4	235 (i)	MAPP coupled IM
Hemp	PP	40	52	4	86	4	210 (i)	MAPP coupled IM
Kenaf (random)	PP	30	46	5	58	4	39 (i)	CM
Flax	PP	30	52	5	60	5	18 (c)	IM
Flax (random)	PLA	30	100	8				Dew retted Stripped/combed (strength 1339 MPa) Film stacking
Flax (random)	PLLA	30	99	9				Dew retted, stripped, combed (strength 1339 MPa) Film stacking
Hemp (random)	PLA	47	55	9	113			
Cellulose (continuous)	Bio-Epoxy		92	9	727	27	26 (c)	RTM
Cordenka[a]	PA	30	120	6				IM
Cordenka[a]	PP	42	90	4	–	–	87 (c)	MAPP coupled IM
Lyocell[a] (carded)	PLA	30	89	9	148	6	52 (c)	CM
Cordenka[a]	PLA	25	108	4	–	–	70 (c)	IM
Lyocell[a] (carded)	PHB	30	66	5	105	5	70 (c)	CM
E-glass (unidirectional)	VE	~60	905	39				
E-glass (aligned)	UP	~60	695	31				CM
E-glass (aligned)	Epoxy	~41			450	21		Pultruded
E-glass (woven)	VE	~59	483	33				
E-glass (CSM)	Epoxy	38–40			250	9		
E-glass (CSM)	UP	~47	201	13	278	11	107 (c)	RTM

BKP = bleached kraft pulp, PALF = pineapple leaf fibre.
PHB = poly(3-hydroxybutyrate), PLLA = L-polylactide acid, PA = Polyamide.
MAA-PP = maleic acid anhydride modified PP.
CSM = chopped strand mat.
[a] Lyocell/Cordenka = regenerated cellulose fibre.
[b] High molecular weight MAPP
[c] Rubbery MAPP.

2.1.2.2 Factors affecting the mechanical properties fibers

The harvesting period influences the properties of the fibers. Some researchers have found that the strength of the fiber reduces by 15% over the 15 days after the optimum harvest time [16]. The harvesting method plays a vital role in the properties of the fibers. Some researches show that the manually extracted flax fibers tend to have a higher strength than the flax fiber harvested by the machine [3]. They have found that the average increment is about 20%.

The moisture contents available in the fiber affect several mechanical properties of the fiber. Some research's have been conducted on the wood fibers at a constant temperature with different moisture content. It is clear that modules of the elasticity, tensile strength, shear strength tends to decrease with the increases of the Moisture content [17]. It is clearly shown by table 4 which the values at two different Moisture content was found and the values are presented as a relative number with respect to the properties at the moisture content 12% [12].

Property	Relative change in property from 12% MC	
	At 6% MC	At 20% MC
	%	%
Modulus of elasticity parallel-to-the-grain	+9	−13
Modulus of elasticity perpendicular-to-the-grain	+20	−23
Shear modulus	+20	−20
Bending strength	+30	−25
Tensile strength parallel-to-the-grain	+8	−15
Compressive strength parallel-to-the-grain	+35	−35
Shear strength parallel-to-the-grain	+18	−18
Tensile strength perpendicular-to-the-grain	+12	−20
Compressive strength perpendicular-to-the-grain at the proportional limit	+30	−30

Table 4 [17].

The temperature has important effects on fiber properties. Literature was found on this effect, where the researchers measure the different properties of wood fiber at two different temperatures. They present the values as a relative number for the properties at the temperature 20 degree Celsius. Throughout the test, the moisture content is let constant although it changes from property to property. Decrease of temperature tends to increase the

elasticity modulus, bending strength, Tensile strength, Shear strength of the fibers which is shown in table 5[17].

Property	Moisture condition	Relative change in mechanical property from 20 C	
		At −50 C	At +50 C
	%	%	%
Modulus of elasticity parallel-to-the-grain	0	+11	−6
	12	+17	−7
	>FSP	+50	—
Modulus of elasticity perpendicular-to-the-grain	6	—	−20
	12	—	−35
	≥20	—	−38
Shear modulus	>FSP	—	−25
Bending strength	≤4	+18	−10
	11–15	+35	−20
	18–20	+60	−25
	≥FSP	+110	−25
Tensile strength parallel-to-the-grain	0–12	—	−4
Compressive strength parallel-to-the-grain	0	+20	−10
	12–45	+50	−25
Shear strength parallel-to-the-grain	>FSP	—	−25
Tensile strength perpendicular-to-the-grain	4–6	—	−10
	11–16	—	−20
	≥18	—	−30
Compressive strength perpendicular-to-the-grain at the proportional limit	0–6	—	−20
	≥10	—	−35

Table 5 [17].

In the composites containing fibers with failure strains lower than that of the matrix. Basic composites theory suggests that there should be a volume fraction of fiber below which composite strength will be lower than that of the matrix known as the critical volume fraction. From a fracture mechanics perspective, below V_{crit},, when the fibers fail, the matrix can cope with load transferred from the failed fibers and the fibers are acting merely as holes within the matrix. Critical volume fractions of fiber have been found to be 8.1% and 9.3% for jute and flax respectively in unsaturated polyester (UP), much higher than values obtained for synthetic fiber composites, although lower than fiber contents commonly studied in the literature and so this effect is not observed often [18].

Fiber dispersion is a major factor influence the properties of short fiber composite and a particular challenge for NFC, which commonly have hydrophilic fibers and hydrophobic matrices. Use of longer fibers can increase their tendency to agglomerate. Better fiber dispersion promotes good interfacial bonding, reducing voids by ensuring fibers are surrounded by the matrix [19]. Dispersion can be influenced by processing parameters such as temperature and pressure.

2.1.2.3 Interface strength

Interface bonding between the fiber and matrix is an important factor for the mechanical properties of the fibers. With a good interface, the stress of the matrix is transmitted for the fibers. The hydrophobic fibers have a limited have a poor interaction with the matrix. The wettability of the fiber is an essential precursor for the interfacial bonding. There are many ways that the researchers have discovered to increase the interface strength.

There are different methods that we can increase the interface between the fibers and the matrix. Sometimes these methods are a single method or a many of them at once.

2.1.2.3.1 Mechanical Locking

Generally, the mechanical interface locking can be done by roughening the surface of the fiber. If the fibers are oriented in one direction, this method only increases the properties in the longitudinal direction and the transverse will remain the same. Some researchers have used electrostatic force to create a better locking between the matrix and the fibers.

2.1.2.3.2 Corona, plasma and UV treatment

Corona treatment uses plasma generated by the application of a high voltage to sharp electrode tips separated by quartz at low temperature and atmospheric pressure and commonly includes the use of oxygen-containing species [20]. It has been shown that the alteration in the physical and chemical properties of fibers occurs. The carboxyl and the hydroxyl groups increases and it results in the increase in the roughness in the fiber and the surface polarity [21][22]. Some researchers have used this method on jute fibers and they have found that although it increases the polarity of the fiber it decreases the strength of the fiber. But overall the flexural strength of the composite increased by 30% which was made of the epoxy matrix. In the above composite, they also used the UV treatment on the composite [22].

Plasma treatment is very similar for the corona the only difference from plasma is that the gas continuously supplied to maintain the appropriate pressure and the gas composition [23]. The researches had found that the flexural strength and the shear strength in natural fiber composites is increased by 35% and 30% respectively [24].

All the above treatments depend on the time, temperature, composition of the gases involved in the process.

2.1.2.3.3 Heat treatment

Heat treatment is the heating of the fiber close to a temperature close to a degradation of a fiber, This can affect the physical, chemical and mechanical properties of the fiber including the water content, cellulose crystallinity, degree of polymerization and strength. A researcher has obtained 60% improvement in the tensile strength in kenaf fiber which he says due to the increase of fiber crystallinity.[25]

2.1.2.3.4 Electron radiation

One of the rare methods used by the researchers is electron radiation. It had shown an improvement of interfacial bonding by a factor of 22%-53 %. suggest that the reason for this improvement is due to the production of free radicals which encourage bonding between the matrix and the fibers.[26]

2.1.2.3.5 Chemical locking

The chemical interlocking happens when a chemical agent reacts with the chemical compounds in the fibers and the matrix and form a bond. The result from this interlocking depends on the type of the bond form and the density of the material. This kind of interlocking is obtained by using the coupling agents [3].

2.1.2.3.6 Alkali treatment

It reduces the amount of the hemicellulose, lignin, pectin, fat and wax that present in the fibers which increase the crystallinity of the fibers. It also increases the crystallinity of the cellulose as alkali remove the obstructs components for the crystallinity of the cellulose [27][28]. As some research's say the alkali treatment increases the strength of the fiber [27][29]. Many researchers have shown that the tensile strength, Young's modulus, failure strain, impact strength, fracture toughness and flexural properties of composites tend to increase. And thermal stability and long-term moisture resistance were observed with alkali treated natural fibers [27-32]. The composites with a crystallizable matrix tend to increase its degree of crystallinity and the reason for this was given as the exposed cellulose acting as a nucleation site for crystalline polymer [33]. Figure 13 shows the difference between the alkali treated and the untreated for Hemp-PLA composite for different fiber volume fraction.

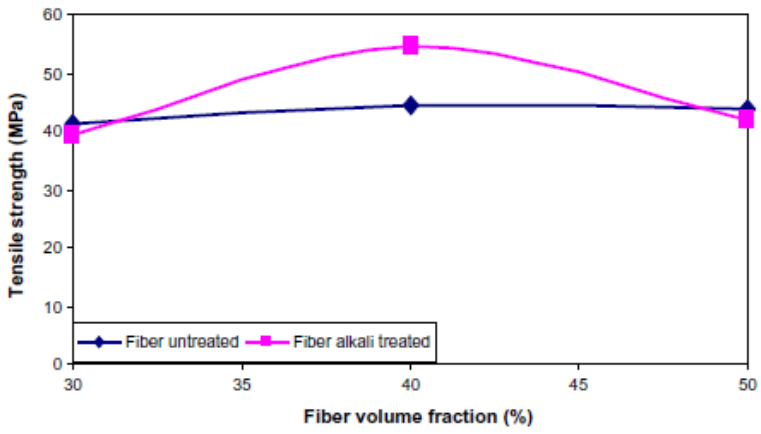


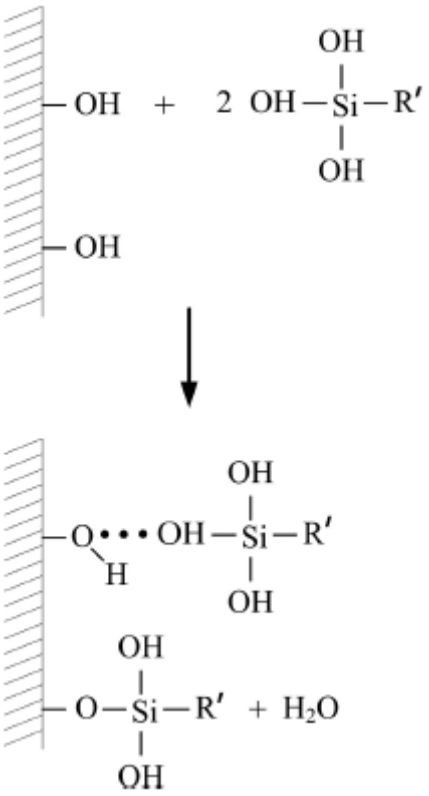
Figure 13 [27].

2.1.2.3.7 Silane treatment

This treatment is done for the fibers with different functional groups at either end which has a hydrophobic group of the fiber, and the other end interact with the hydrophobic group in the matrix and it makes something like a bridge between them.

In the process of silane treatment of the natural fibers involves in the hydrolysis of the alkoxy group on silane with water to form silanol (Si-OH) groups[b]. These can react with hydroxyl

groups on the fiber surface as in figure 14. Most famous silanes used by the researches are amino, methacrylic, glycidyl and alkyl silanes. It was found that silanes increase the hydrophobicity of the natural fibers and strength because of the covalent bonds bonded between the silane and the matrix [34][35].



The Figure 14 [3].

2.1.2.3.8 Maleic Anhydride

These polymers are used as coupling agents which it helps to improve composite properties. The MA is commonly grafted to the same polymer which is used as a matrix This ensure the compatibility between the matrix and the coupling agent for better bonding. It also used as an additive during processing or after the processing.

In most of the literature, the MA is used with PP because it makes MAPP. MAPP is reacted with the hydroxyl groups in the fiber which make the covalent bonds and hydrogen bonds as

shown in figure 15. It has shown that MA helps to improve the tensile strength, stiffness and the impact strength of the MA-treated PP composite matrix [36].

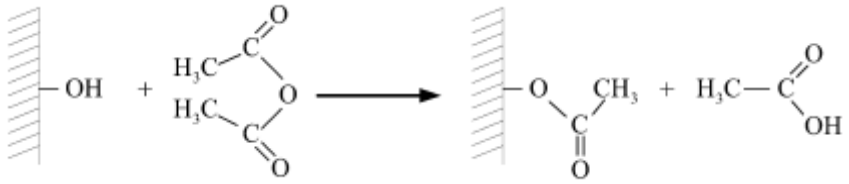


Figure 15 [3].

Figure 16 shows the influence of the mass percentage of the coupling agent on old newsprint-filled PP composite. At 1.5% of MA the best tensile strength is observed.

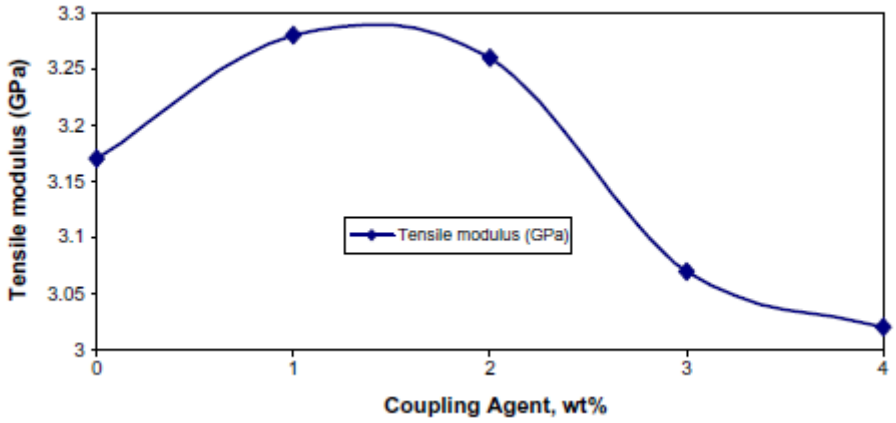


Figure 16 [37].

2.1.2.3.9 Enzyme treatment

An improvement in the composite properties was observed with the application of the enzyme treatment. Especially tensile and flexural strength of abaca and pp composites seen to improve by 45% and 35% respectively [37]. The reason above improvement was stated due to the increase of the surface area for the leading to the increase of the interfacial bonding and further, the impact properties were also found to increase by 25% [37].

2.1.2.3.10 Interdiffusion bonding

This kind of bonding is obtained when atoms and molecules of the fiber and the matrix interact at the interface. For polymer interface, the entanglement of the fibers can provide good interlocking

3. Matrix

The matrix plays and important role in the composites. It acts as a barrier in reinforced composite fiber against the adverse environment, protects the surface of the fiber from the mechanical abrasion and it transfer load to the fibers. The most common matrix used in Natural Fiber composite is Polymeric. They can be processed at a low temperature and it is very light. The evidence of the use of both thermoset and thermoplastic matrices can be found in the literature. Based on the type of the matrix used in the composites can be classified as Natural composites and partial composites.

One of the main obstacles faced by the polymeric matrixes is the processing temperature. Almost all the fiber cannot be processed above 200°C [3]. Therefore, most of the time thermoplastics are used in the composites with the natural fibers. Table 9 shows the commonly used Polymeric matrices.

Thermoset polymer	**Thermoplastic polymer**
Unsaturated polyester	Polyethylene
Epoxy Resin	Polypropylene
Phenol Formaldehyde	Polyolefin
	Polyvinyl Chloride
	Polystyrene

Table 9[3]

Table 10 and table 11 show the mechanical properties of the different polymeric matrices. in thermoplastic polymer nylon 6.6 has the highest tensile strength. While in the epoxy top the tensile strength in the thermoset polymers.

Property	PP[4]	LDPE	HDPE	PS	Nylon 6	Nylon 6,6
Density (g/cm^3)	0.899–0.920	0.910–0.925	0.94–0.96	10.4–1.06	1.12–1.14	1.13–1.15
Water absorption-24 h (%)	0.01–0.02	<0.015	0.01–0.2	0.03–0.10	1.3–1.8	1.0–1.6
T_g (°C)	−10 to −23′	−125	−133 to −100′	N/A	48	80
T_m (°C)	160–176	105–116	120–140	110–135′	215	250–269
Heat deflection Temp (°C)	50–63	32–50	43–60	Max. 220	56–80	75–90
Coefficient of thermal expansion (mm/mm/°C × 10^5)	6.8–13.5	10	12–13	6–8	8–8.86	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 (J/m)	21.4–267	>854	26.7–1068	1.1	42.7–160	16–654

[4] PP = polypropylene, LDPE = low density polyethylene, HDPE = high-density polyethylene and PS = polystyrene.

Table 10 [37].

Property	Polyester resin	Vinyl ester resin	Epoxy
Density (g/cm^3)	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	N/A	1–2
Water absorption (24 h@20 °C)	0.1–0.3	0.1	0.1–0.4
Izod impact strength (J/m)	0.15–3.2	2.5	0.3

Table 10 [37].

3.1 Polylactic Acid

Currently, there can be found bioderived matrices. Polylactic Acid is one of the best-bioderived matrices that can be found in the modern market. Polylactic acid is made out of 100% renewable sources such as corn. PLA belongs to the class of thermoplastic polymers [30]. Figure 17 shows the molecular structure of the PLA.

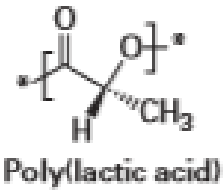


Figure 19 [40].

The PLA produces a lower amount of the carbon dioxides to the atmosphere when compared to the other rival polymers. Table 11 shows the mechanical properties of polylactic acid. According to the table the tensile strength of the PLA polymer of 57 MPa [37]. But the epoxy resin has a tensile strength of 87 MPa [37]. Although the PLA is more sustainable than that of the Epoxy resin, the epoxy resin has higher tensile strength.

Mechanical:		
Tensile strength	Mpa	59
Elongation at break	%	7
Elastic modulus	MPa	3500
Shear modulus	MPa	1287
Poisson's ratio	–	0.36
Yield strength	MPa	70
Flexural strength	MPa	106
Unnotched izod	J/m	195
Notch izod impact	J/m	26
Rockwell hardness	HR	88
Heat deflection temp	°C	55
Vicat penetration	°C	59
Ultimate tensile strength	MPa	73
Percent of elongation	%	11.3
Young's modulus	MPa	1280

Table 11 [37].

4. Case Study

4.1 Coconut fibers

The coconut tree is native for the southeast Asia (Pacific and the Indian ocean tropical islands. There are different kinds of fibers extracted from the different parts of coconut trees. For example, Midrib of coconut palm leaves and Coconut coir fibers extracted from the coconut shell is used in sectors such as automotive, construction field, etc. those fiber show high properties for soundproofing and thermal resistant Out of them the coconut sheath is left without almost unused therefore this example discusses the coconut sheath

4.1.1 Leaf sheath

Coconut leaf sheath is present in the trunk of the stem which leaves are connected to the trunk. The sheath always occurs in the form of the mat. The sheath is mainly made up of an inner mat which is sandwiched between two layers of course fibers.

Figure 17 [38].

4.1.1.1 Process to separate to mats

The leaf sheaths collected from the trees were dipped in water for one week, thoroughly washed with tap water followed by distilled water, and dried in the sun for a week. Cleaned leaf sheath was separated to inner sheath mat and the outer layer fibers. The fibers of the inner matt and outer layers were separately kept in hot air for 24 h at 105−110ºC to remove the moisture. Some of these fibers were treated with 5% aqueous sodium hydroxide (NaOH) solution for one hour at room temperature, maintaining a liquor ratio of 25:1 to remove the hemicellulose and other greasy materials. These fibers were washed with water repeatedly and treated with dilute acetic acid to neutralize them. Finally, the fibers were washed with distilled water before drying in a hot air oven for a period of 24 h [39].

4.1.1.2 Mechanical Properties

There are mainly two kinds of fiber present in the sheath. They can be known as Inner mat fine fiber and Outer layer coarse fiber. The main significant difference between these fibers are the length to diameter ratio is significantly larger in the inner matt fine fiber as shown in Table 6.

Fiber	Length (L) (cm)	Diameter (D) (cm)	L/D Ratio
Inner mat fine fiber	47.5	0.014	3322
Outer layer coarse fiber	47.5	0.099	478

Table 6 [39].

The researcher has found the number of constituents in each kind of fibers separately. And also they have found the amount of the cellulose, hemicellulose, and lignin after the alkali treatment as shown in table 7. Properties of the flax fibers are given in table 8 for the comparison.

Fiber	Untreated			Treated		
	Cellulose	**Hemicellulose**	**Lignin**	**Cellulose**	**Hemicellulose**	**Lignin**
Inner mat	34.3	29.1	36.4	40.2	16.8	42.9
Coarse	53.6	22.3	24	60.5	12.5	26.9
Flax	72	14	5	-	-	-

Table 7 [39][37].

Both the inner mat and the outer matt can be made rough by alkali treatment[e] which increase the interface with the resin. Due to the alkali treatment, the hemicellulose in the fiber is removed. As a result of internal strain is released the fibrils become more packed and rearranging themselves in a more compact manner. The tensile properties tend to increase as a result of closed packed fibrils [39] as shown in table 8. The degradation temperature for the alkali treated fibers are slightly larger than the untreated.

Fiber	Untreated			Treated		
	Maximum stress (MPa)	**Youngs module (MPa)**	**Elongation %**	**Maximum stress (MPa)**	**Youngs modules (MPa)**	**Elongation %**
Inner	119.8	18	5.5	128.6	6.8	8.7
Coarse	94.3	4.4	6.3	196.8	5.2	5.7
Flax	800	60	3.0	-	-	-

Table 8 [39][37].

The moisture content of the alkali treated fibers is smaller than the untreated. As thermal stability is directly proportional to the moisture content. The alkali treated fibers are more thermally stable and as the fibrils are closely packed the permeation of water into them is minimum. Due to the thermal stability of the alkali treated fiber, it gives the opportunity for a thermoplastic matrix with higher processing temperature of 275 °C [39].

The crystallinity of the fibers can be measured by the X-ray diffraction. The intensity of the crystallinity is given by equation 2.

$$Ic = \frac{I_{(002)} - I_{(am)}}{I_{(002)}} * 100$$

Equation 2 [39].

I_{002} standard for the intensity of the crystallinity peaks which is obtained at a reflection angle of 22°[e]. And I_{am} standard for the amorphous which is obtained at the reflection angle of 16°[e]. It is clear that alkali treated fibers have higher crystallinity according to figure 18.

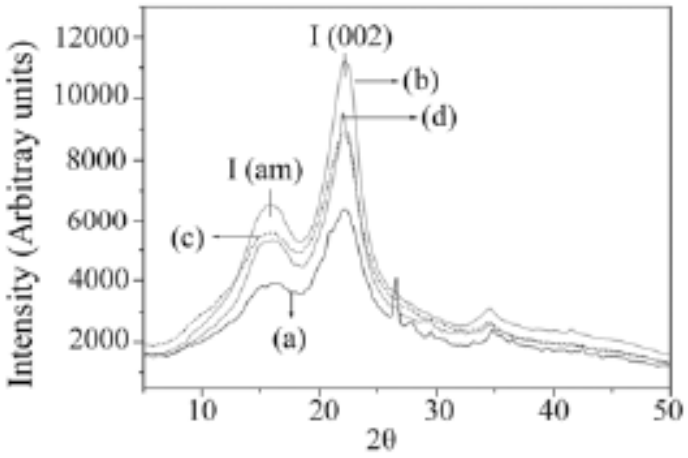


Figure 18 [39].

a-Untreated leaf sheath inner mat fibers; b-Alkali treated leaf sheath inner mat fibers; c-Untreated leaf sheath coarse fibers from outer layer; d-Alkali treated leaf sheath coarse fibers from outer layer.

4.2 Experiment

4.2.1 Testing on composite

An experiment on the coconut sheath was produced in the lab at Politecnico di Torino. The ultimate's goal of this experiment measured the tensile strength, flexural strength and bending fatigue strength of the coconut sheath composite with the epoxy resin. In performing the experiment following standards shown in Table 12 was used for each study. The composite made was not 100% natural because we used epoxy resin as our matrix.

Standard	Test
D3039/D3039M	Tensile test.
D7264/D7264M	Flexural strength.
D7774-17	Fatigue bending test.

Table 12.

4.2.1.1 Preparation of the specimen

Three kind of specimens were made from the above made composite. Which named them as A, B and C. The three species varies from each other based on the orientation of the fiber and the kind of the fiber. The A and C specimens have the coarse fibers aligned in the composite. Sheath was directly used in B specimens. Totally 3 specimens for A and 3 specimens for C and 4 specimens for B was made. A piece of sheath was taken and some coarse fibers were extracted. Then some epoxy resin was made by mixing the epoxy and resin. Prepared epoxy resin was applied on the special piece of paper which the composite is layered. Then carefully the sheath is placed and more epoxy resin is applied on the top of the mat. By using another piece of paper, the composite is squeeze gently in order to assist the resin to flow into the mat. Then the setup is left for some cooling. Then the pieces are cut out from harden composite. A little notch is glued to the top and bottom of the specimen to have good grip for the tensile testing machine. Specimens were rubbed by using a sandpaper to avoid defect due to cutting. Above finished specimens are shown by the figures from 20 to 29.

The amount of mass of coconut sheath and the mass of resin goes inside composite was measured. The density of the coconut sheath was obtained from the literature [41]. But this number change on the dryness of the sheath. Similarly, the density of the epoxy resin was found from the literature [42]. In this apparatus we had assumed that the composite is homogenous. The values are shown in the table 14.

	A	**B**	**C**
M_{tot} (g)	62	44	92
$M_{coconut\ fiber}$ (g)	8	6.5	14
M_{resin} (g)	54	37.50	78
$P_{coconut\ fiber}$ (gcm^{-3})	1.2	1.2	1.2
P_{resin} (gcm^{-3})	2.09	2.09	2.09
$V_{coconut\ fiber}$ (cm^3)	9.6	7.8	16.8
V_{resin} (cm^3)	112.86	78.375	163.02

Table 14.

The precision of the balance used to measure the weights is 0.0001g. By using a calliper with the precision of the 0.05mm the dimensions of the specimen were measured and given in table 15.

Figure 14.

Figure 15.

Figure 16.

Figure 17.

Figure 18.

Figure 19.

Figure 20.

Figure 21.

Figure 22.

Figure 23.

Specimen	Average Width (cm)	Average Length (cm)	Average Thickness (cm)	Mass (g)	Volume (cm^3)
A1	1.910	11.05	0.340	7.3876	7.17587
A2	2.228	11.073	0.330	8.411	8.14131252
A3	2.105	11.688	0.310	7.3656	7.6270044
B1	1.983	12.708	0.2	4.92725	5.0399928
B2	2.205	7.873	0.145	2.19215	2.517194925
B3	2.065	6.150	0.185	2.1466	2.34945375
B4	2.065	7.573	0.225	2.5793	3.518605125
C1	2.065	13.203	0.475	14.2074	12.95049263
C2	2.460	13.653	0.44	15.0621	14.7780072
C3	2.345	7.015	0.49	8.623	8.06058575

Table 15.

Out of the above specimens on a random basis, the specimens are selected for the different tests. Those selected specimens are given in table 16.

The test	Specimen
Tensile test	A3, B1, C1, C2
Flexural strength test	A1, A2, C3
Fatigue bending test	B2, B3, B4

Table 16.

4.2.1.2 Testing

The goal of the testing was to find the ultimate tensile strength and the following strain. By using the above properties, the elastic modulus of the composite was calculated.

Equipment list

- Four specimens given in table 16.
- Tensile test machine MTS
- Strain gauge

Procedure

- The specimen was placed in the grooves of the tensile machine.
- The strain gauge was positioned in the setup.
- The tensile test was started
- Above steps were repeated for all the specimens

The test was conducted as a deformation rate of 5mmmin^{-1}.

4.2.1.3 Results

During the test, out of the 4 specimens, 2 specimens was broken from the right middle and the other two was broken at one end of the specimen. The data obtain from the tensile testing machine was the Force vs Instantaneous Length of elongation. As we know the initial lengths of the specimen from the table 15 the stress was calculated by dividing the force by the initial cross section of each specimens and the strain was calculated from the initial length by using the equation 2 and the equation 3 respectively. Graph was draw by using the above calculated numbers.

$$\boldsymbol{\sigma = \frac{F}{A}}$$

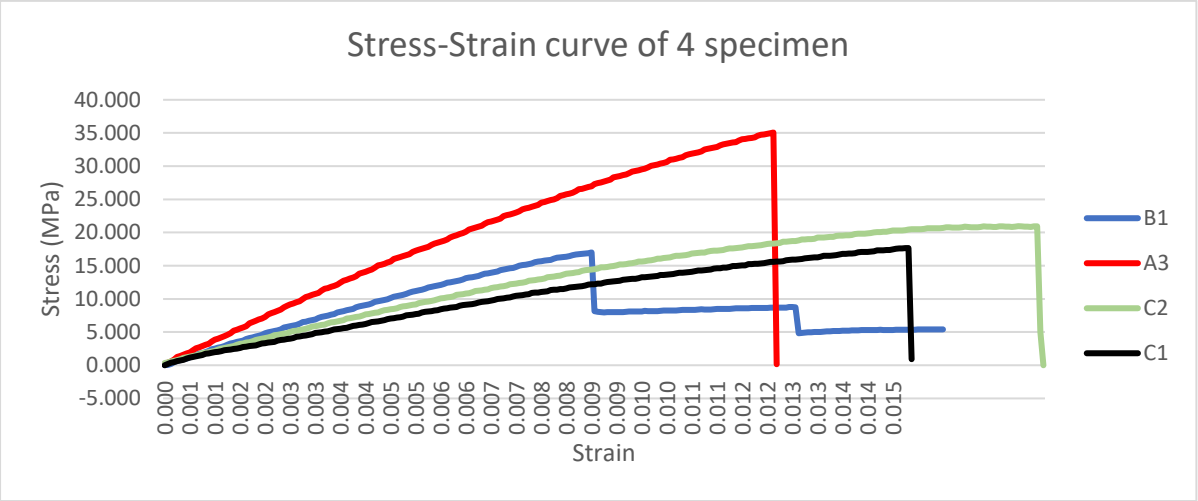
Equation 2.

$$\varepsilon = \boldsymbol{\frac{\Delta l}{l_o}}$$

Equation 3.

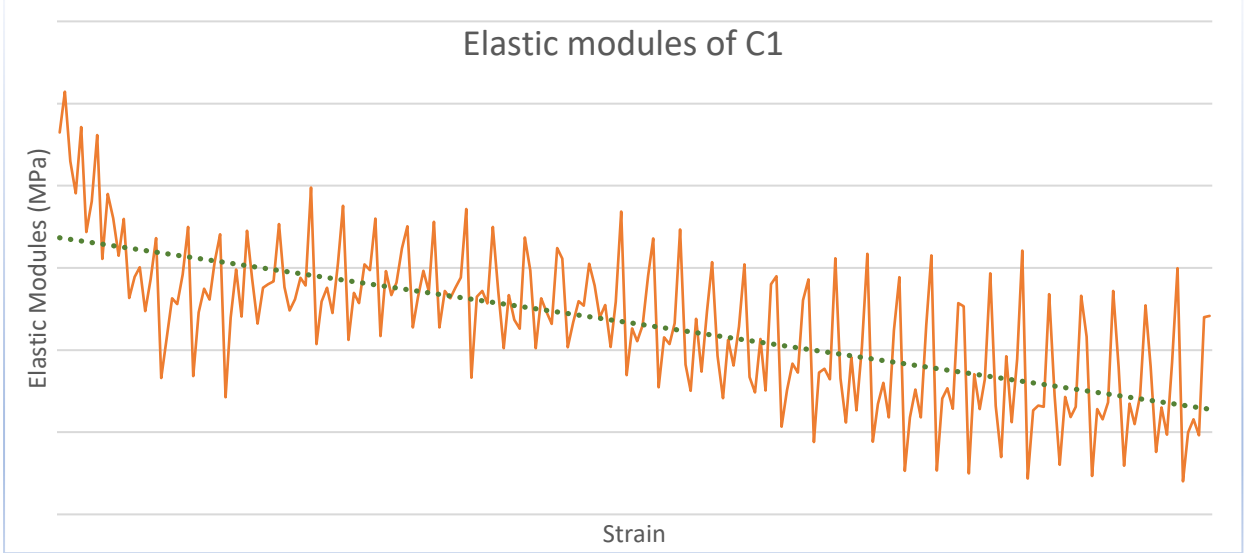
Specimen B1 was broken in two steps and it has very low ultimate stress compared to the specimen A3. The data of the specimen B was not included because the matrix was broken before the fiber. The specimen A3 has the highest ultimate tensile strength of 35.065 MPa.

The specimens C1 and C2 have almost the same ultimate tensile strength but the specimen C2 has a bit higher stress at the fracture and the it strains more than the C1.

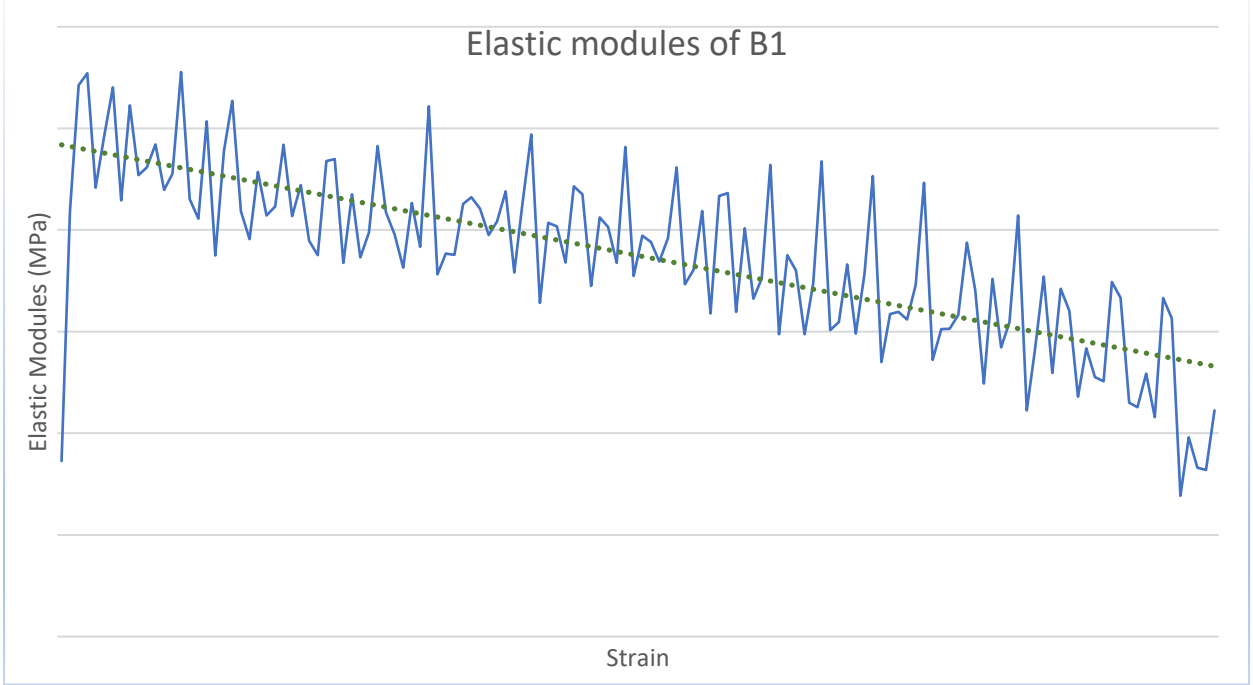


Graph 1.

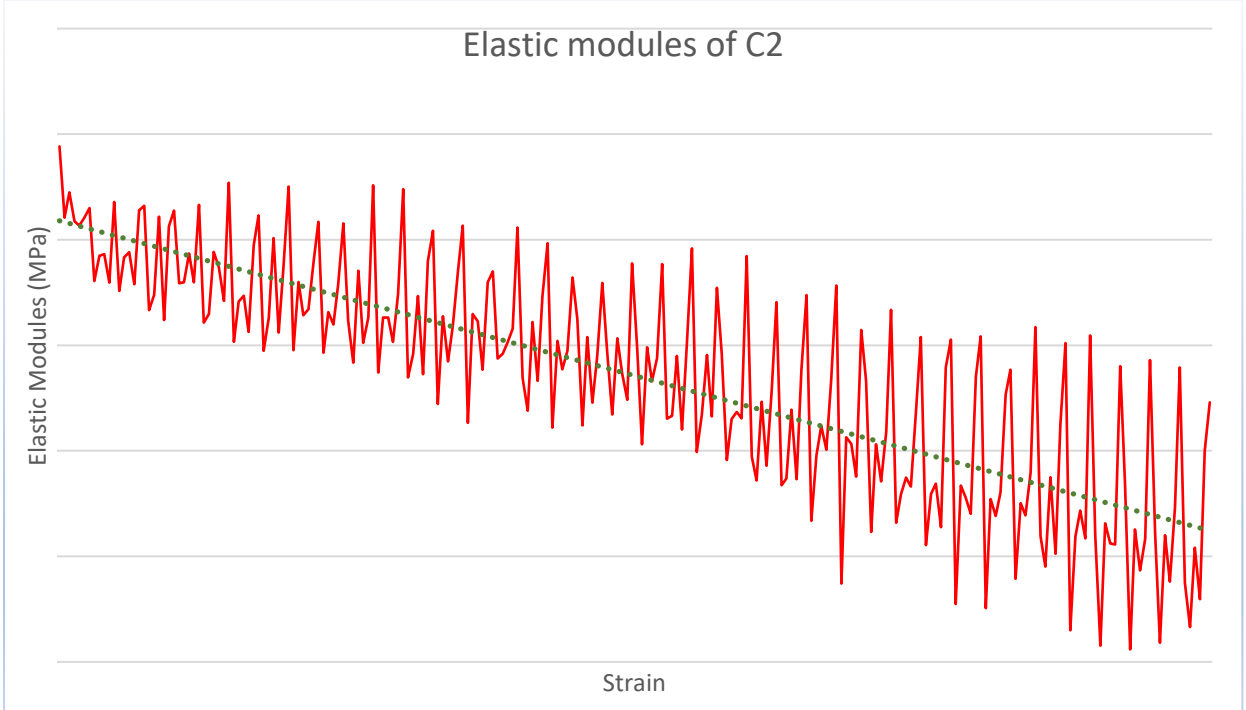
The elastic modules for each specimen was found in two ways. First the least square method was used and the secondly the instantaneous elastic modules of each specimen was calculated. The graph 2, 3, 4,5 shows the instantaneous elastic modulus for each specimen. For the B1 specimen only the values until the first break is taken. In order to define a common elastic modulus for the whole process the average from above calculated valves was calculated A trend of decreasing elastic modules with the increase of strain was observed in the all four specimens.



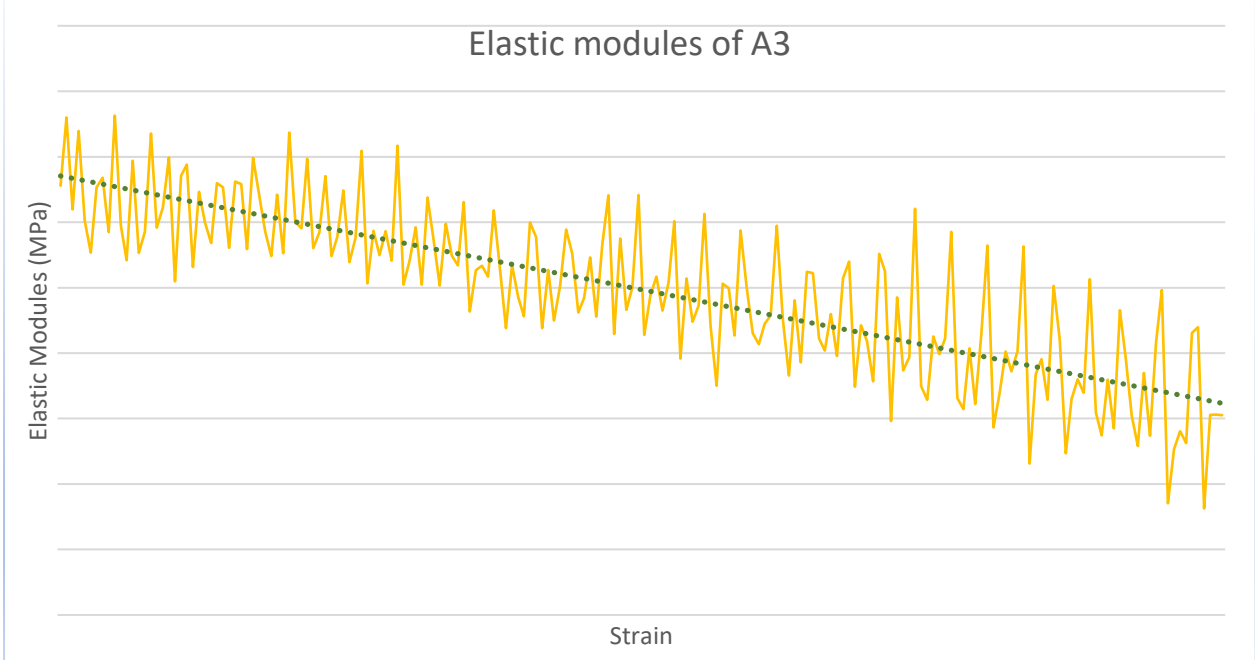
Graph 2.



Graph 3.



Graph 4.



Graph 5.

The table 16 shows the elastic modules for each specimen in both above methods. The maximum stress and the maximum strain before the failure is given in the table 16. A the specimen B1 had a bad fracture it data was not included. But for the specimen B1 the elastic modules were calculated.

Properties/Specimens	**A3**	**B1**	**C1**	**C2**
Maximum Stress	35.065	-	17.654	20.955
Maximum Strain	0.016	-	0.015	
Elastic modules by the average	2485.102	1874.764	1161.651	1355.800
Elastic modulus by the least square method	2560.351	1938.830	1177.055	1266.209

Table 16.

Out of the above given two type of the elastic modules there are no significant differences observed. The figure 24 show the broken pieces from the tensile test. The tensile strength of the epoxy resin is known as around 82 MPa [42]. But the tensile strength of the composite is

lower than that as shown in the Table 16. The possible reason for this can presented as due to the available porosity in the composite as we did not vacuum the composite. Another possible reason is lack of interface strength between the fibers and the matrix.

C2 B1 C1 A3

Figure 24.

The data of this experiment was shared between the Ettore Lupica who worked with we in the same material. The results of the fatigue and the flexural strength is given in his thesis.

4.2.2 Testing on fibers

The fibers used for the above composite and some other fibers from coconut tree was tested was tested separately. The fiber were extracted from the two places randomly. Some fibers were taken from the sheath and some fibers were taken from the coconut shell.

4.2.2.1 preparation of the specimen

The mass of the fibers was weighted and the length was measured by a ruler. In order to measure the diameter of the fiber a square paper was used an fibers was place on it as shown in the figure 25. Then by using the scaling method the diameter was method.

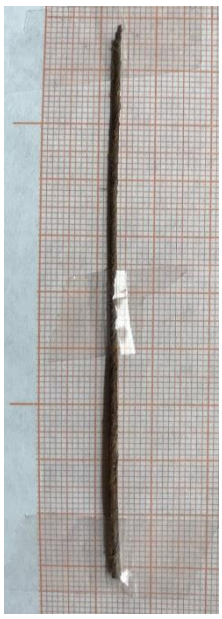


Figure 25.

The fibers was differentiated on the fact that were it was extracted as small fibers for the coconut shell and the large fibers from the sheath. The physical dimensions of the small fibers and large fibers are given by the table 17 and table 18 respectively. In the tables 17 and 18 the density of the fibers are given.

Fiber no.	Length (mm)	Mass (g)	Diameter (mm)	Density (g/mm^2)
1	64	0.003	0.5	2.39E-04
2	62	0.0052	0.65	2.53E-04
3	59	0.0019	0.85	5.68E-05
4	66	0.0029	0.5	2.24E-04
5	62	0.0153	1	3.14E-04
6	63	0.0023	0.4	2.91E-04
7	68	0.0037	0.35	5.66E-04
8	58	0.0037	0.45	4.01E-04

Table 17.

Fiber no.	Length (mm)	Mass (g)	Diameter (mm)	Density (g/mm^2)
9	95	0.099	3	1.47E-04
10	103	0.1219	1.95	3.96E-04
11	106	0.0956	1.96	2.99E-04
12	89	0.1218	3.1	1.81E-04
13	106	0.1959	3.2	2.30E-04

Table 18.

4.2.2.2 Testing

All the above 13 fibers were subjected to tensile test. The goal of the testing was to find the ultimate tensile strength, elastic modulus and the following strain. By using the above properties, the elastic modulus of the composite was calculated.

Equipment list

- Thirteen fibers given in the tables 17 and table 18.
- Tensile test machine MTS
- Strain gauge
- 50 N load cell and 500N load cell

Procedure

- The specimen was placed in the grooves of the tensile machine and a piece of a paper was placed to increase the roughness.

- The strain gauge was positioned in the setup and first the 50N load cell was loaded.
- The tensile test was started
- Above steps were repeated for all the specimens in the table 17.
- Then the load cell was change to 500N and the strain gauge was positioned.
- The tensile test was carried out for the fiber in the table 18.

The test was conducted as a deformation rate of 2mmmin^{-1}.

4.2.2.3 Results

The data obtained from the test was in the form of load (N) to elongation (mm). By using the measured diameter, the cross section was calculated. Using the cross-section area and the initial length the stress and the strain was calculated by using the equation 2 and equation 3. By using those data, the stress strain curve was drawn for the small and the large fiber as shown in the figure 26 and 27 respectively.

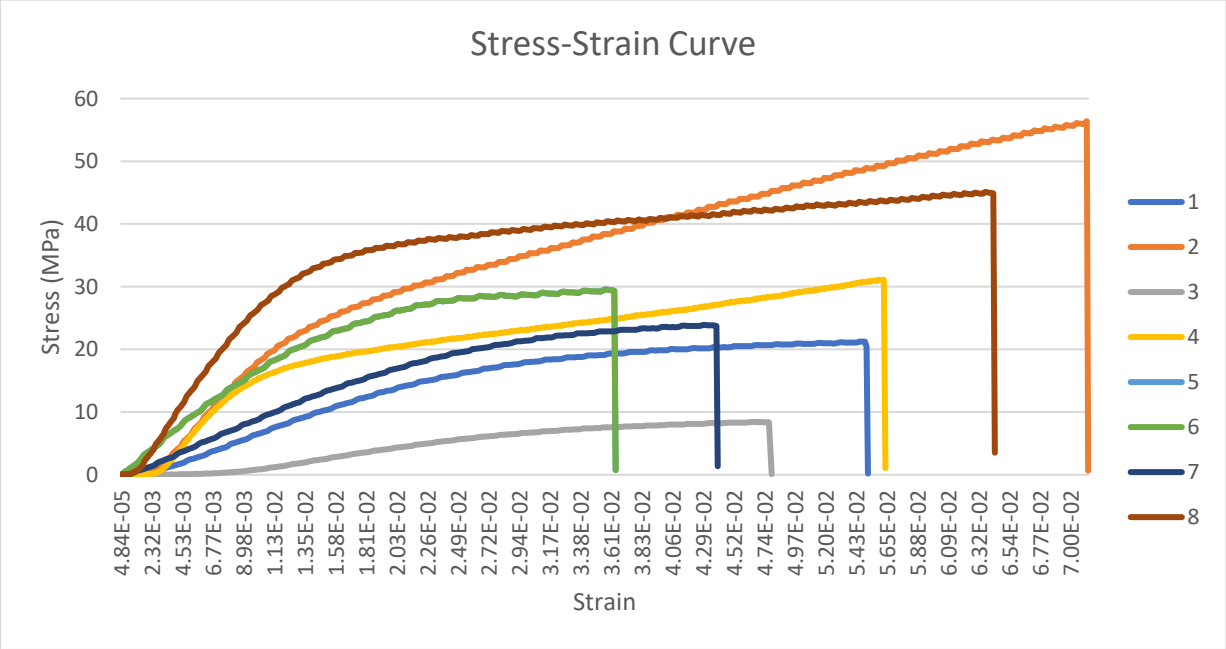


Figure 26.

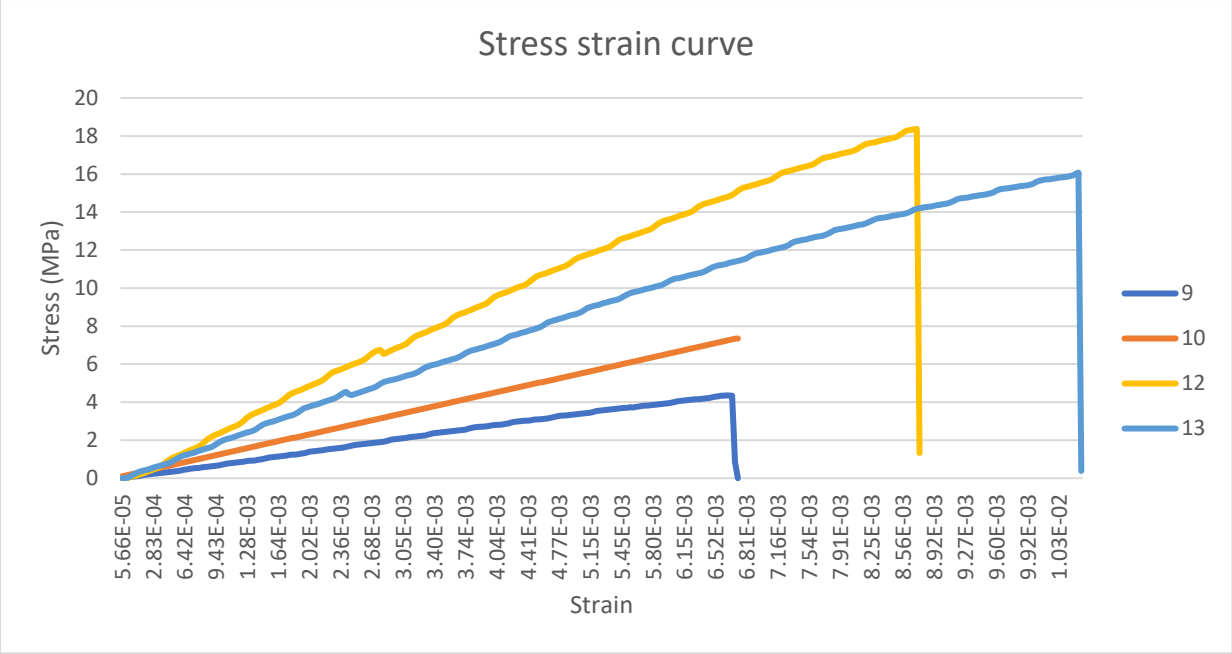


Figure 27.

While running the test the fiber no. 1, 6, 8 was broken at the grip. Therefore in calculating the elastic modules the data from the above fiber was not included. The figure 28 shows a perfect break observed which is fiber no. 7.

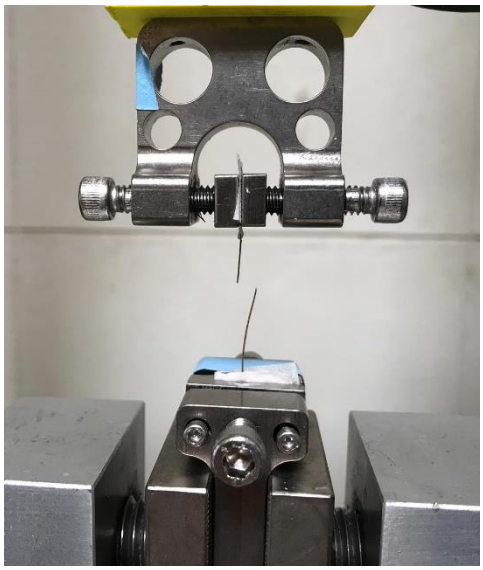


Figure 28.

The data of the fiber 11 was excluded because at the middle of the testing some slipping was observed. There elastic modules were calculated instantaneous and the average was taken in the area where the stress and strain is linear. For the two kind of the fiber which the results are given in the table 19 and table 20. The maximum stress and the strain were measured and documented in the table 19 and table 20.

Fiber	Elastic Modulus (MPa)	Maximum Stress (MPa)	Maximum Strain
1	1391.222	21.26	2.66E-02
2	1741.382	48.96	5.51E-02
3	558.329	8.41	2.50E-02
4	1178.178	30.89	1.04E-01
5	1339.005	19.77	2.15E-02
6	3529.720	29.56	1.78E-02
7	1852.781	23.91	1.96E-02
8	2361.257	43.52	5.77E-02

Table 19.

Fiber	Elastic Modulus (MPa)	Maximum Stress (MPa)	Maximum Strain
9	580.711	4.35	0.008
10	2217.601	14.56	0.007
11	-	-	-
12	1765.369	18.38	0.010
13	1512.035	16.08	0.011

Table 20.

From the above table the strength of the fibers differ from one to another in large scale. The fiber no. 3 has the lowest stress and it has the lowest density. The fiber no. 2, 3, 4 are the fiber with the highest stress and the density of the fibers are larger compared to the others. Therefore, we can say that there is a proper relation between the stress and the density.

The fiber extracted from the sheath had shown lower ultimate tensile strength than the fibers extracted from the shell. These fiber were stiff than the fiber from the coconut shell.

5. Conclusion

The goal of the 100% sustainable materials is not an easy goal to achieve. But day by day we are getting close for it. I hope eventually we reach over there. In fabricating a snowboard 100% eco-friendly we have to face lots of challenges. Although it is possible to make a composite structurally fit enough for the purpose most of the time composite is not 100% natural. Already in the market there are many natural fibers which is suitable for the task. For example, Flax, hemp and basil some of the best choices but most of the resins available in the market are made as a petroleum by-product. Therefore, there is more opportunity for research's in bio resins.

Throughout this thesis mechanical properties of the different fibers was discussed. There were factors affecting the strength of the fiber. Temperature and the Moisture content was two of the main factors. It was shown that the increase in the moisture content tends to decrease the mechanical property such as tensile, elastic modules. One of the potential cure for the problem is alkali treatment. It removes an amount of hemicellulose and lignin which are high water absorbing constituents in the fiber. Similarly, some researches showed that the alkali treatment increased the thermal stability of the fiber. Therefore, the alkali treatment is a two in one solution as the fiber degrade at high temperature. Some other factors such as harvesting method and harvesting time have small effects on the mechanical properties of the fiber.

Another main topic discussed in this thesis was the interface strength. The interface strength between the matrix and the fiber is very important. A good interface between fiber and the matrix allow matrix to transport the stress to the fiber otherwise the effectiveness of the composite is very slow. There are many methods to increase the surface strength. Mainly it is three kind Mechanical locking, Chemical locking, Interdiffusion locking. In mechanical locking mainly the surface roughness is the key factor. Anything which can increase the surface rough increase the interface strength. In chemical locking the chemicals are used to create bonds between the fiber and the matrix. Silane treatment one example and maleic anhydride is used as a coupling agent. Treatments like alkali treatment affect the internal structure of the fiber and at the same time increase the surface roughness facilitating the mechanical locking. Interdiffusion locking is making bonds between the matrix and the fiber and the factors such as entanglement of the fibers improve the interface strength.

A case study of coconut sheath and coconut fibers was performed. Naturally sheath exists as a matt. Researches have conducted the experiment on the single fibers after separating them into two layers of fiber. The researchers have measured the mechanical properties of them and the tensile strength of flax fiber is 8 times higher than that of coconut sheath fibers. And researchers have conducted the experiment on alkali treated and the untreated fibers. It was found that the mechanical properties of the alkali treated fibers are better. But one of the advantages of the coconut sheath is that it is bonded naturally on 2 layers, use of this sheath without separating them increase the mechanical properties of the composite itself and in two directions.

An experiment was conducted on coconut sheath with the epoxy resin. In making the samples the orientation and the different kind of the fibers were chosen. The tensile test was carried out on the above fabricated samples. In those samples the highest stress of 35.065MPa and a lowest of 17.65 MPa was obtained. These number prove that the orientation of the fibers and the type of the fiber selected is a significant factor. The elastic modules were found in the range of 2560.31MPa – 1266.029MPa. Comparing the above results with the sisal-epoxy 410 MPa [3] which is the highest values ever achieved with natural fiber it has a quite low value.

The second experiment was conducted on the coconut fibers. The coconut fibers were extracted from 2 places. Some of the fiber were extracted from the sheath and the some fibers were extracted from the coconut shell. It was observed that there is s clear relationship between the density of the fiber and the ultimate tensile strength. Fibers with the lower density tend to have lower ultimate tensile strength while the fiber with the higher density tend to have higher tensile strength. The highest ultimate tensile strength recorded was 48.96 MPa. The fiber from the sheath broke at lower stress compared to the fibers from the coconut shell but these fiber were stiffer than the fiber from the coconut shell. Some fibers like the fiber from the shell was observed in the sheath and it was tested which tend to have similar properties from the coconut shell. Comparing the coconut fibers to the flax fiber, the UTS of the flax fiber stand between the values of 600-800 MPa [3]. But the maximum UTS recorded by our experiment was 48.96 MPa, which is relatively low.

Based on the results of the experiments conducted it is crystal clear that the coconut fibers have low mechanical properties compared to the other natural fiber used in the industries in the present day. The composite of the sheath and the resin tend to have a lower tensile strength than the resin itself. Therefore, it is not a good choice for the snowboard. But these

fiber still can used for the occasion which require lower ultimate tensile strength and the non-structural purposes. One of the main advantage use of the coconut fibers is due to it abundancy and the low cost in processing. Fibers in the shell is used current in the different field but the literature regarding the use of fibers from the sheath industrially was not recorded.

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