Investigation of the use of stinging nettle fibres (*Urtica Dioica*) for polymer reinforcement: Study of single fibre tensile properties.

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ABSTRACT

Developing new natural fibre composites is the focus of many studies today. Indeed, they are made out of renewable resources and, therefore, have a lower environmental impact in comparison to mineral fibre composites. The mechanical performances of stinging nettle fibres are measured and compared to flax and other lignocellulosic fibres. The stress/strain curve of stinging nettle fibres (*Urtica dioica*) shows they have a linear behaviour. Tensile stiffness and strength decrease as the fibre diameter increases. The average tensile properties are a Young's modulus equal to 87 GPa, a tensile strength equal to 1594 MPa, and a strain at failure equal to 2.1%.

1. INTRODUCTION

In the past decades, ultimate waste and pollution has been increasing very fast. Finding new alternatives and taking into account the end of life of a product as early as the design stage are crucial to reduce the impact of mass consumption on the environment.

Fibre reinforced polymers have a high property over weight ratio and their use in structures of all kinds (aerospace, marine, automotive, wind energy etc.) is increasing. One of their main drawbacks is recycling since it is a very difficult process which has a high cost. Nowadays, glass fibre composites are usually burnt in cement factories or grinded and used as fillers. Only in 2005, over 7 million tones of composites were produced and in a few years they will represent as much waste.

In the last decade, developing natural fibre composites has been the focus of many studies. These offer many new benefits such as a lower impact on the environment, the possibility to biodegrade the fibres at the end of their useful lifespan etc.

Natural fibres can be divided into three groups, i.e. lignocellulosic fibres (e.g. flax, hemp, sisal), protein fibres (e.g. wool, silk, chitin) and, mineral fibres (e.g. asbestos). Lignocellulosic fibres are renewable and have good mechanical properties hence justifying their use as reinforcement in polymers.

Nettle is a common herbaceous plant which regroups 30 to 45 species. It is part of the *Urticaceae* family such as ramie (Asian nettle, *Boehmeria nivea*) and belongs to the genus *Urtica*. The stinging nettle (*Urtica dioica*) is the most prominent species in Europe. It grows in rich soils and up to 1.20 m high.

One of the main interests of nettle is that the entire plant can be used for various purposes such as food, fodder, medicine, cosmetic, biodynamic agriculture, and textile production [1-5]. Table 1 shows some of these applications and their benefits.

Nettle and hemp were used since the prehistoric times as alternatives to flax. Hemp was used for its long and strong fibres whereas nettle produced a “finer and silkier” fabric than flax [1]. However, during the 20th century the textile industry abandoned the use of nettle fibres for technical and cost-effectiveness reasons: fibre extraction could not entirely be mechanized and as soon as the cost of labour increased, farming nettles was not profitable, and the cultivation ceased [3]. This was emphasized by the powerful cotton industry which took over the smaller textile industries such as flax, hemp, and nettle.

What?	Applications	Comments/benefits	References
Textile	Rope & string	During World War 1, 85% of the German's clothes were made out of nettle fibres. The green colour of unbleached nettle fibres was used for camouflage.	[3]
	Cloth	Nettle thread was used in Poland in between 12th & 17th century until it was replaced by silk. In the 1940's, 500ha of nettles were grown in Germany/Austria and 70ha in Great Britain for textile applications.	[1,2,4]
Food/drinks	Soup/stew	It is firstly boiled to remove the sting and then used in soup or stew like spinach. It is an excellent source of vitamin C, Mg, Fe, Ca and numerous trace elements.	[5]
	Tea	Stimulates proliferation of lymphocytes, provides arthritis relief, stimulates hair growth, reduces hair loss, diuretic etc.	[5]
Agriculture	Fodder	Feeding cows with dried nettles (to remove the sting) increases their milk production. Horse breeders added seeds to fodder to give the animal a sleek coat.	[5]
	Fertilizer	Nettle compost or nettle manure (achieved by soaking nettles in water for a few weeks) are excellent fertilizer.	[6]
Cosmetic	Hair	In tea, nettle seeds stimulate hair growth and reduce hair loss. It is used in commercial shampoo and has the same effects.	[5]
	Skin	Cleaning and cleansing ability.	[5]
Medicine	Vasoconstrictor	In tea, helps contracting blood vessels hence increasing blood pressure.	[3]
	Arthritis	Urtication with freshly cut nettles was used to smooth arthritis.	[5]
	Diuretic	Fresh nettle tea has been used to treat prostate conditions.	[5]
	Healing	Fresh leaf juice applied to cuts aids blood coagulation and formation of haemoglobin	[5]
	Digestion	Stimulates gastric and intestinal flow, pancreatic and biliary secretions	[5]

Table 1: Stinging nettle applications

As flax and hemp, nettle fibres are biodegradable, they require little energy to produce and, they are extracted from a renewable resource. Ideally, biocomposites made out of a biodegradable matrix (such as a biopolymer) and natural fibres could be manufactured, used, grinded, and recycled naturally in a compost heap [7]. The present paper analyses the tensile properties and section of nettle fibres which could be used in new eco-friendly composite materials. The tensile properties of nettle fibres are compared to those of various vegetable fibres.

2. EXPERIMENTS

Materials:

Stinging nettles were harvested in France (Brittany region). At the end of September, the nettle stems were cut at the base and dried for two day before being retted in water for 7 days. They were then dried at room temperature for several weeks. The fibres were manually extracted with a great deal of care to avoid any damage.

Scanning electron microscopy (SEM):

50 mm stem fragments were placed in ethanol and distilled water solution for at least 10 days before being sliced and dried at room temperature. Their morphology was examined by scanning electron microscopy, using a JEOL JSM-6031F. The cross section surface of 363 nettle fibres was measured using an optical microscope.

Single fibre tensile tests:

Single nettle fibres were glued onto a slotted paper holder (10 mm gap equal to L_0 the nominal length of the fibre). Tensile tests were carried out on a MTS Synergie 1000 apparatus equipped with a 2 N load cell which has an accuracy of 0.01%. The accuracy of the displacement is ± 1 µm. The loading speed is 1 mm/min. ASTM D 3379-75 standard was used throughout this study. The compliance of the system was taken into account to correct the fibre stiffness E_f:

$$E_f = \frac{L_0/S_0}{\frac{L_0/S_0}{E_a} - C_0} \qquad (1)$$

With S_0 the cross section area of the fibre (assuming it is circular in shape), E_a is the measured stiffness and, C_0 the compliance of the load cell.

Before the test, each sample was observed with an optical microscope and the fibre diameter was measured. The results presented i.e. Young's modulus, stress and strain at failure are average values and were measured for 90 fibres.

3. RESULTS AND DISCUSSION

The cross section of a nettle stem was examined by SEM (Figs. 1). The fibre bundles (which can be seen as a thin layer <100µm) are located on the outside perimeter of the stem (Fig. 1a). Fig. 1b shows the fibres have a polygonal cross section and it appears they have a lumen in their centre.

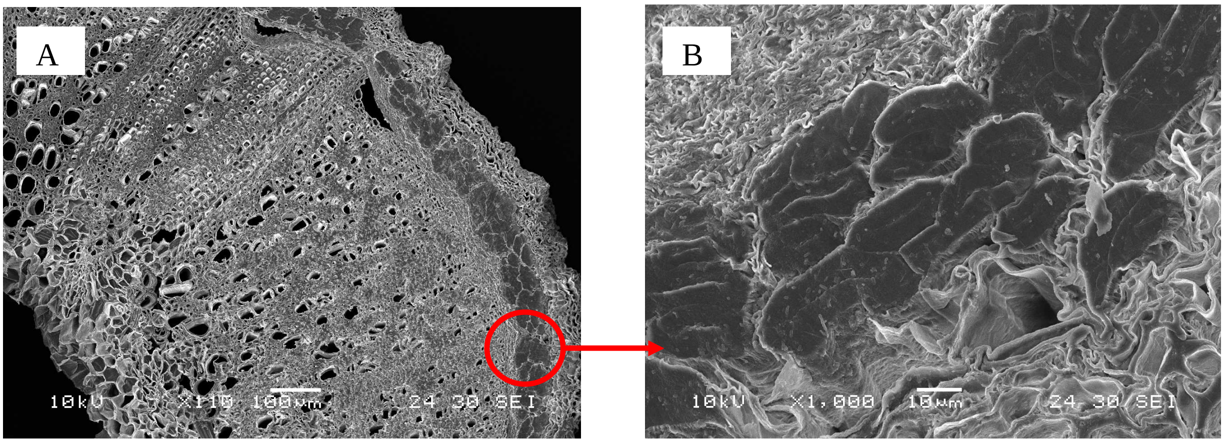


Figure 1: SEM photographs of the cross section of a stinging nettle stem (Urtica Dioica); a) Fibre bundles at the outer radius of the stem, b) Polygonal cross section & lumen (in the centre) of fibres

The cross section surface of single fibres was measured. One can consider that they have a circular section which yields easier calculation of an average diameter. The fibres' average diameter is 19.9 µm (± 4.4).

Fig. 2 shows a typical stress/strain curve of a single nettle and flax fibre. As can be seen, nettle fibres have a linear behaviour in comparison to flax.

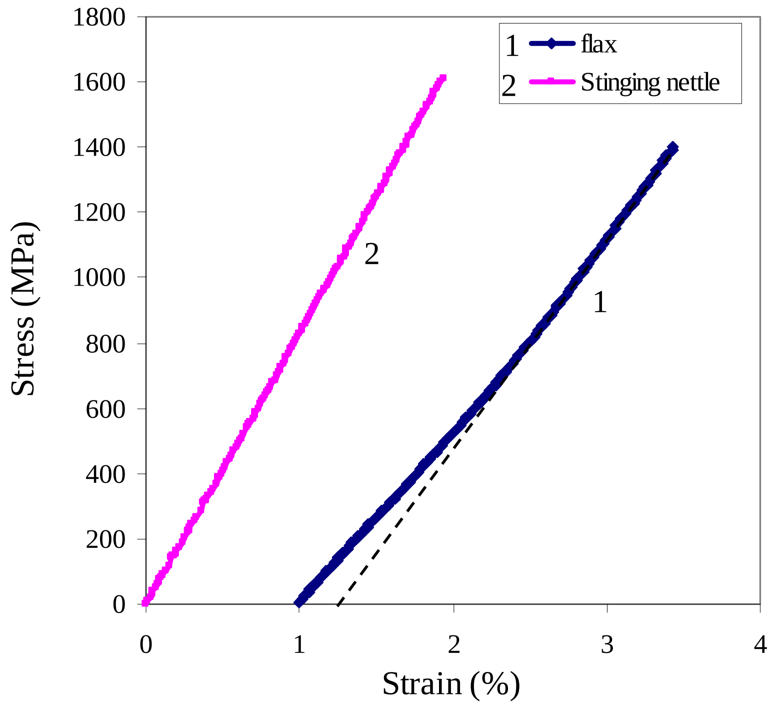
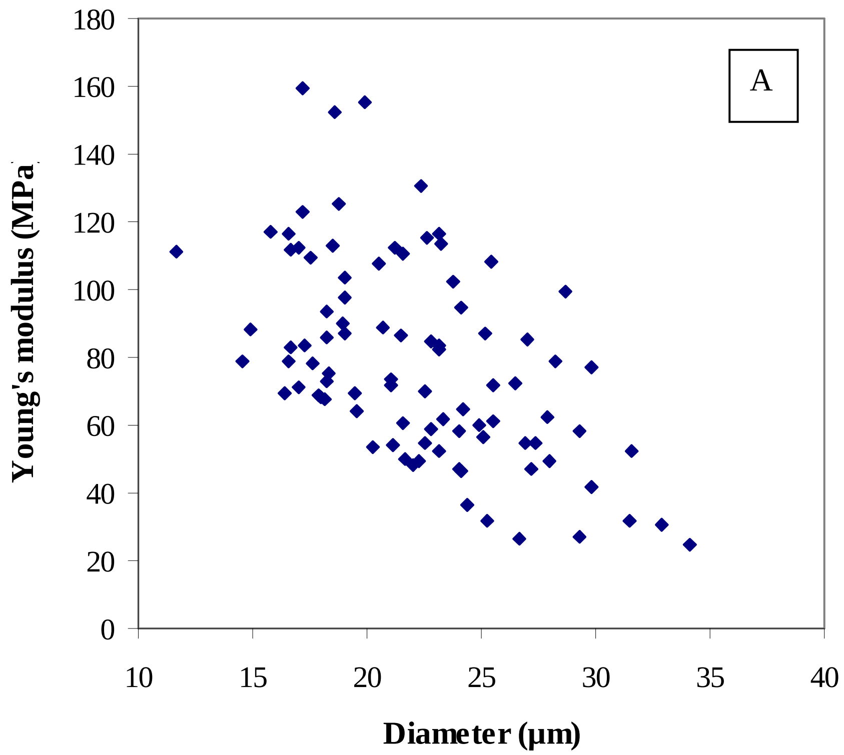


Figure 2: Typical stinging nettle fibre and flax stress/strain curves.

The tensile behaviour of vegetable fibres mainly relies on their cellulose composition and, moreover, on the orientation of the microfibrils. The microfibrils in flax have a 10° angle with regard to the fibre axis [8]. Baley [9] showed that the first part of the stress/strain curve of a flax fibre corresponds to the rearrangement of the microfibrils in the loading direction. This is not noticed for stinging nettle fibres (Fig.2). Nishiyama et al. [10] showed that the fibril angle of ramie fibres was estimated to be 3°. Ramie and stinging nettle are part of the same family. The linear behaviour of stinging nettle fibres can be explained by the orientation of the microfibrils and reveals they have a small tilt angle.

In figures 3a-3b, Young's modulus and ultimate stress of single stinging nettle fibres are plotted as a function of the fibre diameter. For practical reasons, the fibres are considered to be perfect cylinders. One can notice the reported values are widely scattered. Dispersion in mechanical properties is inevitable for vegetable fibres. One of the reasons to this is the lumen: it is not taken into account since it is difficult to determine its dimensions. Consequently, significant calculation errors are generated which can affect the Young's modulus value. Despite the results are widely scattered, the stiffness and strength of the fibres decrease when the fibre diameter increases (Fig. 3). The same behaviour is noticed for flax fibres [9].



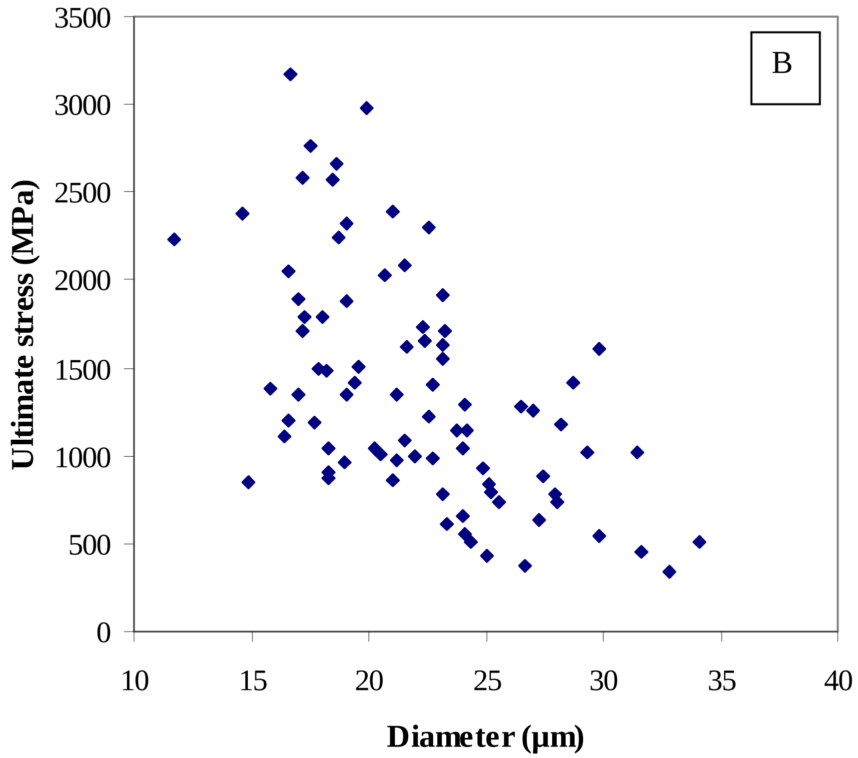


Figure 3: Stinging nettle fibre, tensile properties:
a) Stiffness as a function of fibre diameter; b) Strength as a function of fibre diameter

The average tensile properties are a Young's modulus equal to 87 GPa (± 28), a tensile ultimate stress equal to 1594 MPa (± 640) and, a strain at failure equal to 2.11% (± 0.83). These values correspond to the average mechanical properties of a subset of fibres whose diameters were 20±2 µm, the mean values calculated from the morphological analysis (28 characterized fibres).

Table 2 compares the tensile properties of single nettle fibres to other lignocellulosic fibres and, glass fibres which is the most common fibre used to reinforce polymers.

	Young's modulus (GPa)	Ultimate stress (MPa)	Strain to failure (%)	Density (g/cm^3)	Average diameter (µm)	References
Stinging nettle	87 (± 28)	1594 (± 640)	2.1 (± 0.8)		19.9 (± 4.4)	[11]
Flax ariane	58 (± 15)	1339 (± 486)	3.27 (± 0.4)	1.53	17.8 (± 5.8)	[9]
Flax agatha	71 (± 25)	1381 (± 419)	2.1 (± 0.8)	1.53	15 (± 0.6)	[12]
Hemp	19.1 (± 4.3)	270 (± 40)	0.8 (± 0.1)	1.48	31.2(± 4.9)	[13]
Ramie	65 (± 18)	900		1.51		[14]
Ramie	24.5	560	2.5	1.51	34	[15]
Glass	72	2200	3.0	2.54		[16]

Table 2: Tensile properties of single fibres

The comparison shows the stiffness of stinging nettle fibres is greater than that of glass fibre. The density of stinging nettles is more likely to be close to 1.5g/cm^3. Lignocellulosic fibres are lighter than glass and consequently, the property over density ratio is a lot more interesting for stinging nettle fibres than it is for glass. For this reason, stinging nettle and flax fibres for instance, can be considered as high performance reinforcements.
According to literature, hemp, ramie and, sisal have inferior tensile properties to stinging nettle and flax. Yet, no conclusion can be made on the properties of the first 3 fibres mentioned. Indeed, the species of the plants are not mentioned, nor the growing conditions, the way the fibres are extracted and, how the measurements are carried out. Finally, for a given plant there are many varieties. This parameter influences the characteristics of fibres and is illustrated for flax (Ariane and Agatha varieties) [9,12].

4. CONCLUSIONS

Developing new eco-friendly materials is a great challenge. Stinging nettle (*Urtica Dioica*) has many interesting properties. The whole plant can be used in either medicinal, human or crop food, and textile applications.
This study proves nettle fibres have very interesting tensile properties and could also be suitable as reinforcing components in composite materials.
The stress/strain curve of stinging nettle fibres is linear. The Young's modulus and ultimate stress depend on the fibre diameter. Further studies will be carried out to determine the composition/structure of the fibres (more particularly the cellulose percentage and micro fibril tilt angle) and, the behaviour of polymers reinforced by stinging nettle fibres.

ACKNOWLEDGEMENTS

The first author particularly wishes to acknowledge:

- the Brittany Region, Cap Lorient and the Morbihan subdivision for their financial support,
- L2PIC laboratory (Lorient University) where this study was carried out.
- Vestas Wind Systems A/S for their support and help to make the presentation of this work happen at ECCM13.

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