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Lanzilao, G, Goswami, P orcid.org/0000-0003-1488-409X and Blackburn, RS orcid.org/0000-0001-6259-3807 (2016) Study of the morphological characteristics and physical properties of Himalayan giant nettle (Girardinia diversifolia L.) fibre in comparison with European nettle (Urtica dioica L.) fibre. Materials Letters, 181. pp. 200-203. ISSN 0167-577X

https://doi.org/10.1016/j.matlet.2016.06.044

Study of the morphological characteristics and physical properties of Himalayan giant nettle (Girardinia diversifolia L.) fibre in comparison with European nettle (Urtica dioica L.) fibre

Gabriella Lanzilao, Parikshit Goswami, Richard S. Blackburn*

Sustainable Materials Research Group, School of Design, University of Leeds, Leeds, LS2 9JT, UK.

*Corresponding author: Tel: +44 113 343 3757; Fax: +44 113 343 3704; E-mail address: r.s.blackburn@leeds.ac.uk

Abstract

Development of sustainable fibres for high performance applications is challenging because of the high mechanical strength properties demanded by such fibres and the general lack of such properties in natural fibres. The mechanical properties of Himalayan giant nettle (Girardinia diversifolia L.) fibre are measured and compared to those for European nettle (Urtica dioica L.) fibre. The mean length of G. diversifolia fibre is substantially higher than U. dioica fibre, and the longest fibre length reported for any bast fibre. G. diversifolia and U. dioica fibres have similar cross-sectional area, but G. diversifolia fibre is a wider, flatter, oval shape with a significantly wider lumen. G. diversifolia fibre display a generally linear stress/strain curve. Ultimate stress value for G. diversifolia fibre is over twice that of U. dioica fibre, and the highest of any bast fibre reported. G. diversifolia fibre also displays greatest strain at failure of any bast fibre. Young’s modulus for G. diversifolia and U. dioica fibre are similar. Himalayan giant nettle fibres display tensile properties that offer potential in high performance applications.

Keywords: Fibre technology, Nettle, Girardinia diversifolia, Urtica dioica, Mechanical properties, Biomaterials.

1. Introduction

The textile market is increasingly focusing on sustainable fibres [1], and those that also have specific physical properties suitable for high performance applications (high wear-resistance, breathability, and thermal insulation [2,3]) are particularly desirable [4]. The current high performance fibre market is dominated by synthetic fibres (e.g. carbon fibre, polyethylene terephthalate, polyurethane, polytetrafluoroethylene), which present problems in their disposal and/or recycling. Bast fibres sit within the intersection of sustainability and performance materials; they are obtained from stems of dicotyledonous plants and are characterized by their thinness, flexibility, and strength [5-7]. Cellulosic bast fibres are generally less expensive than synthetic fibres and possess competitive mechanical properties, such as high tensile, due to the volume fraction of cellulose [8] and the microfibrillar orientation [9].

Himalayan giant nettle (Girardinia diversifolia L.) grows in tropical Africa (from Ethiopia to Madagascar), Yemen, Nepal, India, Sri Lanka, southern China, Taiwan and Indonesia [10], and bast fibres from the plant are traditionally are used to make ropes, twine, fishing nets, sacking and some clothing, but fibre production is currently very low in comparison with other natural fibres [11]. G. diversifolia grows at 1000-2500 m above sea level, in areas of partial shade; the plant, which grows tall (1.5 to 3.0 m high), strong, and erect, needs an environment with good moisture content, high velocity winds, low temperatures (the plant is frost-resistant for 3-4 days), in fertile, deep, drained soil. Shade is important and when the plant grows in sunny areas fibres are dark and difficult to work, while shade-grown plant is so white bleaching is unnecessary [11]. Harvest is between August and December, when the fibre is white and of a better quality; local farmers usually hand-cut the plants during the cold seasons as the effect of stinging is considerably reduced by lower temperatures [12]. The processes for fibre extraction is currently by hand using natural retting processes; caustic soda treatment for fibre extraction is not currently used. Himalayan Wild Fibers LLC has already embarked on the industrial scale-up of G. diversifolia fibre production in Nepal.

Bodros & Baley provide an introduction to and discussion of the tensile properties of European nettle (Urtica dioica L.) [13], but there is limited literature available on the properties of G. diversifolia fibre. Herein, an investigation into the physical properties of G. diversifolia fibre was performed in comparison with U. dioica fibre. These values were compared to literature values for other bast fibres.

2. Experimental

2.1 Materials

Himalayan Wild Fibers LLC (HWF) kindly provided retted and dried Himalayan Giant nettle (G. diversifolia) fibres. Retted and dried European nettle (U. dioica) fibres, Clone 13, were kindly provided by DeMontfort University, UK. All chemicals were of general laboratory grade provided by Aldrich.

2.2 Fibre selection and extraction

The fibres investigated were randomly selected from a supply of 1.84 kg of raw G. diversifolia fibres, and from a supply of 1 kg of U. dioica fibres. Fibres were manually extracted (with a great deal of care not to damage the fibre) from the bundle with tweezers, ensuring only that single fibres were extracted. Prior to testing, fibres were conditioned for at least 48 hours at 65 % relative humidity and 20 ± 2 °C.

2.3 Length measurements

The length of each fibre (L) was measured using a steel ruler and a graph paper. 50 extracted G. diversifolia fibre specimens and 50 extracted U. dioica fibre specimens were sampled and an average of these fibre lengths calculated, according to methods described in BS ISO 6989:1981 [14].

2.4 Transmission Electron Microscopy (TEM) and cross-sectional area measurement

50 extracted G. diversifolia fibre specimens and 50 extracted U. dioica fibre specimens were stained using osmium tetroxide (OsO_4) and embedded in epoxy resin. To 50 cm^3 LR white resin was added 0.1 g of supplied catalyst. Fibre samples were immersed in the resin in size 4 gelatine capsules and the capsules kept in an oven at 60 ± 2 ºC for more than 24 h to ensure resin solidification. Sections approximately 80-90 nm thick were taken using a Reichert-Jung Ultracut E Ultramicrotome with a diamond knife. A Jeol 1200EX transmission electron microscope was used to analyse the samples; the size and the outline of the fibre cross-sections were obtained by processing TEM images using ImagePro (6.2). For this analysis program option segmentation was used, which uses a grayscale with the values of 1 = black and 0 = white; using a reference scale of the image magnification it was possible to calculate the area, diameter, lumen size, effective surface area, and shape of the fibres.

2.5 Tensile tests

Tensile testing was performed in accordance with EN ISO 5079:1995 [15] on 50 samples each of G. diversifolia fibre and U. dioica fibre. Fibre specimens (20 mm length glued onto a paper holder) were analysed using an Instron 1026 UK apparatus at a loading speed of 50 mm min^{-1} using a load cell with a maximum load limit of 0.5 kg. This load was ideal to test U. dioica fibre, but after observing the strength of G. diversifolia fibre, a load cell with a maximum load limit of 5 kg was used instead [16]. Load values increase in response to the delivered strain, since the curve between load and elongation is a linear function (Hooke's law) and given that the extensional strain indicates the elongation of a specimen during a tensile test in proportion to its original length [17]. No preloading was applied prior to measurement. Average values for force at break (F) and extensional strain at break (ε) were measured.

Stress (σ) is calculated using Equation 1, where cross-sectional area (A) is the actual cross-sectional area, calculated by subtraction of the fibre lumen area from the area of the whole fibre in the image. Stress was calculated by using average A values for extracted fibres, sampled and measured as described in 2.4. σ has units of N m^{-2} (Pa).

$$\sigma = \frac{F}{A} \tag{1}$$

Young's modulus (E) is calculated using Equation 2; E also has units of N m^{-2} (Pa).

$$E = \frac{\sigma}{\varepsilon} \tag{2}$$

3. Results and discussion

Fibre length measurements show that the mean length of G. diversifolia fibres is substantially longer than U. dioica fibre, and also longer than other common bast fibres (Table 1). This suggests that the G. diversifolia fibre is the longest bast fibre reported (478 mm); U. dioica fibre measured herein is significantly shorter (52 mm), similar to those reported by Bacci et al. in their work on U. dioica cultivated in Italy (39-63 mm) [4]. Analysis of the cross-section of both nettle fibres reveals that on average G. diversifolia fibre has a similar A (479 μm^2) to fibres from U. dioica (456 μm^2), which are generally greater than other common bast fibres. TEM analysis of the shape of the nettle fibre cross-sections (Figure 1) reveals that G. diversifolia fibre typically is much wider, flatter and oval-shaped, whereas U. dioica fibres are more circular in cross-section; it is also notable that G. diversifolia fibres have a significantly wider lumen.

Table 1. Physical and tensile properties of single fibres with standard deviation (SD).

Fibre	**L (mm)**	**A (μm^2)**	**σ (MPa)**	**ε (%)**	**E (GPa)**
G. diversifolia	478 (±21)	479 (±186)	4451 (±1313)	6.2 (±1.3)	73 (±22)
U. dioica	52 (±2)	456 (±199)	2196 (±809)	2.8 (±0.9)	79 (±29)
U. dioica (literature)	50 (±12) [4]	311 (±152)* [13]	1594 (±640) [13]	2.1 (±0.8) [13]	87 (±28) [13]
Flax	27 (±3) [18]	183 (±87) [19]	1339 (±486) [20]	3.3 (±0.4) [20]	54 (±15) [20]
Hemp	20 (±5) [18]	764 (±260)* [21]	270 (±40) [21]	0.8 (±0.1) [21]	19 (±4) [21]
Ramie	135 (±15) [18]	270 (±93) [19]	560 [22]	2.5 [22]	24.5 [22]

*value calculated ($A = \pi r^2$) based on literature diameter values, assuming a circular cross-sectional area.

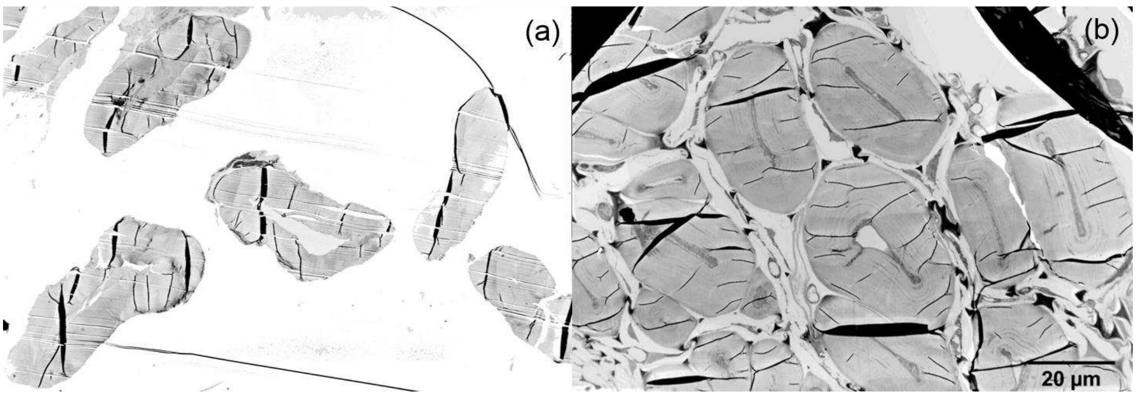

Figure 1. Representative examples of cross-sectional profiles of raw (a) G. diversifolia and (b) U. dioica fibres. TEM photographs 700x magnification.

Figure 2 shows a typical stress/strain curve of a single G. diversifolia fibre, and it is observed that the fibres have a generally linear behaviour, which was also observed for U. dioica fibres herein and by Bodros & Baley [13]; this linear behaviour can be explained by the orientation of cellulose microfibrils and suggests that they have a small tilt angle.

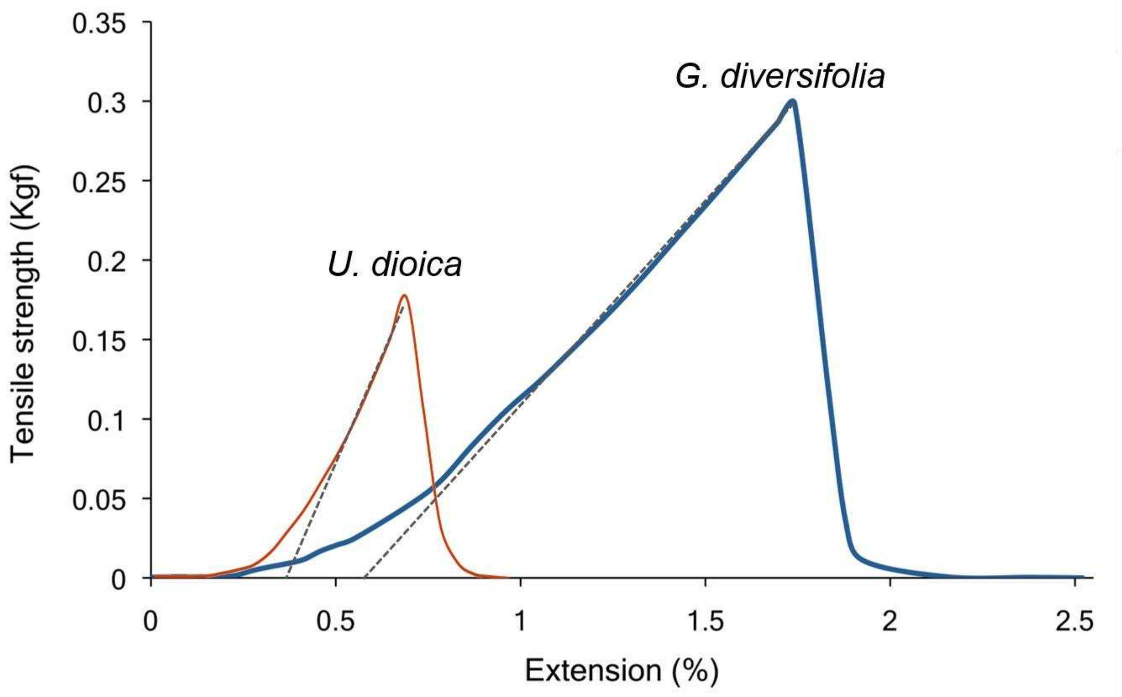

Figure 2. Typical G. diversifolia and U. dioica fibre stress/strain curves. For comparison with other fibres force load (kgf) is converted to stress average (N m^{-2}; MPa).

From Table 1 is can be seen that the tensile properties of U. dioica fibre measured herein compare well with literature [13]. A comparison of tensile properties of the two nettle fibres shows that σ for G. diversifolia fibre (4451 MPa) is over twice that of U. dioica fibre (2196 MPa). In comparison with other bast fibres, σ of U. dioica is closest to values reported for flax (1339 MPa), while G. diversifolia values are the highest of any bast fibre reported and higher even than those reported for some industrial fibres, such as S-glass (4570 MPa) and carbon fibre (4000 MPa) [23].

G. diversifolia fibre also displays greater ε (6.17%) in comparison with U. dioica fibre (2.79%); the value for U. dioica fibre compares well with literature (2.11%) [13]. Comparing these ε values with other bast fibres, it should be noted that the value of G. diversifolia fibre is greater than that of the most common bast fibres and that the value of U. dioica fibre is in the range of values determined for flax and ramie. Summarily, G. diversifolia fibre has superior tensile properties to U. dioica fibre, being more flexible and stronger.

Young's modulus for G. diversifolia fibre (73 GPa) is similar to that for U. dioica fibre (79 GPa); despite G. diversifolia fibre having over double the σ value of U. dioica fibre, E is similar for both nettle fibre types due to the greater extensibility of G. diversifolia fibre; the value for U. dioica fibre compares well with literature (87 GPa) [13]. E for both nettle fibres is generally higher than those of other common bast fibres (see Table 1) and cotton (12 GPa), and is similar to that for and E-glass (73 GPa) [24].

It is noted that SD for the fibre properties in Table 1 are significant in some cases, but these variations are comparable with other fibres from literature considering the magnitude of the properties in comparison; for example, σ SD was ±29% for G. diversifolia and ±37% for U. dioica herein, in comparison with ±40% for U. dioica [4] and ±36% for flax [20] in literature; E SD was ±30% for G. diversifolia and ±36% for U. dioica herein, in comparison with ±32% for U. dioica [4] and ±28% for flax [20].

It is acknowledged that differences in fibre processing methods prior to measurement of properties can influence the results, however, fibre processing herein was generally similar to comparative fibres featured in Table 1. In Bodros & Baley's work, U. dioica stems were cut, retted, and dried at room temperature [13], mirroring the processing of both nettle species herein; similar retting and drying processes were also used for flax [20], hemp [21] and ramie [22]. Preparation differences are noted in some cases. Length measurements for ramie and flax fibres were from yarns that had been degummed with mild alkali and bleached [19], which may have influenced fibre length measurements (from fibre breakages due to damage), although the differences caused by this processing would be expected to be minimal, and the values stated are typical in literature. Tensile measurements for hemp fibres were from plant material that after retting had been soaked in hydrogen peroxide for 48 h; this may have had some influence on fibre properties (caused by fibre swelling and/or damage), but again the differences from this particular treatment would be expected to be minimal. After processing, in all literature cases, single fibres were manually extracted [13, 19-22], as were fibres from both nettle species herein.

4. Conclusions

Development of sustainable fibres for high performance applications is challenging because of the high mechanical strength properties demanded by such fibres and the general lack of such properties in natural fibres. The mean length of G. diversifolia fibre is substantially higher than U. dioica fibre, and G. diversifolia fibre has the longest fibre length reported for any bast fibre. G. diversifolia and U. dioica fibres have similar cross-sectional area, however, the shape of G. diversifolia fibre is typically much wider, flatter and oval-shaped in comparison with the more circular cross-section of U. dioica fibre; G. diversifolia fibres have a significantly wider lumen. G. diversifolia fibre displays a generally linear stress/strain curve as observed for U. dioica fibre. The ultimate stress value for G. diversifolia fibre is over twice that of U. dioica fibre, and the highest of any bast fibre reported. G. diversifolia fibre also displays greater strain at failure in comparison with U. dioica fibre and most common bast fibres. Young's modulus for G. diversifolia fibre is similar to that for U. dioica fibre, and both nettle fibres generally have higher Young's modulus in comparison with other common bast fibres.

These interesting properties present significant opportunities for nettle fibre, particularly Himalayan giant nettle (G. diversifolia) fibres, for use in high performance applications. High tensile properties may provide fibres with high strength, high resistance or significant elasticity; the large cross-sectional area combined with a large lumen potentially also offer a fibre with good insulation properties. These properties in a sustainable, renewable fibre must open opportunities in performance apparel at least, and are certainly superior to other bast fibres where limitations in their properties may reduce potential in this area. Work to develop applications for these fibres is ongoing.

Acknowledgments

The authors thank The University of Leeds for the provision of a scholarship to GL to enable her to conduct her PhD studies.

References

1. R.A. Gross, B. Kalra, Biodegradable polymers for the environment, Science. 297 (2002) 803-807.

2. W. Gindl, K.J. Martinschitz, P. Boesecke, J. Keckes, Changes in the molecular orientation and tensile properties of uniaxially drawn cellulose films, Biomacromol. 7 (2006) 3146-3150.

3. K.C. Schuster, F. Suchomel, J. Männer, M. Abu-Rous, H. Firgo, Functional and Comfort Properties of Textiles from TENCEL® Fibres Resulting from the Fibres' Water-Absorbing Nanostructure: A Review, Macromol. Symp. 244 (2006) 149-165.

4. L. Bacci, S. Baronti, S. Predieri, N. di Virgilio, Fiber yield and quality of fiber nettle (Urtica dioica L.) cultivated in Italy. Ind. Crops Prod. 29 (2009) 480-484.

5. R.R. Franck, Bast and Other Plant Fibres, Woodhead Publishing, Cambridge, 2005.

6. D. Klemm, B. Heublein, H.-P. Fink, A. Bohn, Cellulose: Fascinating biopolymer and sustainable raw material. Angew. Chemie. 44 (2005) 2-37.

7. A.K. Bledzki, J. Gassan, Composites reinforced with cellulose based fibres, Prog Polym. Sci. 24 (1999) 221-274.

8. W.E. Morton, J.W.S. Hearle, Physical Properties of Textile Fibres. Woodhead Publishing, Cambridge, 1993.

9. C. Bergfjord, B. Holst, A procedure for identifying textile bast fibres using microscopy: Flax, nettle/ramie, hemp and jute, Ultramicroscopy. 110 (2010) 1192-1197.

10. M. Brink, Girardinia diversifolia (Link) Friis, in: M. Brink, E.G. Achigan-Dako (Eds.), Prota 16: Fibres/Plantes à fibres. Prota, Wageningen, 2009.

11. T.P. Barakoti, K.P. Shrestha, Commercial utilization of Allo (Girardinia diversifolia) by the Rais of Sankhuwasabha for income generation, Banko Janakari. 18 (2008) 18-24.

12. R. Sherestha, Exploitation of Nettle Fibre in the Makalu-Barun Conservation Area, Publication Series No. 22, Makalu-Barun Conservation Project, Department of National Parks and Wildlife Conservation, HMG/Nepal, and Woodlands Mountain Institute, Mount Everest Ecosystem Conservation Program, Franklin, West Virginia, USA, 1994.

13. E. Bodros, C. Baley, Study of the tensile properties of stinging nettle fibres (Urtica dioica), Mater. Letts. 62 (2008) 2143-2145.

14. BS ISO 6989:1981, Textiles fibres. Determination of length and length distribution of staple fibres

(by measurement of single fibres), BSI Group, 2002.

15. EN ISO 5079:1995, Textiles Fibres Determination of breaking force and elongation at break of individual fibres, BSI Group, 1996.

16. C. Schilling, Standard operating procedure for the Instron machine, 2001. Available at: http://www.mse.iastate.edu/files/2013/11/instron-4204-instructions-schilling-2001.pdf

17. B. P. Saville, Physical testing of textiles. Woodhead Publishing, Cambridge, 2002.

18. R. R. Mather, R. H. Wardman, The chemistry of textile fibres, Royal Society of Chemistry, Cambridge, 2015.

19. L. Cheek, L. Roussel, Mercerization of Ramie: Comparisons with Flax and Cotton. Part I: Effects on Physical, Mechanical, and Accessibility Characteristics, Text. Res. J. 59 (1989) 478-483.

20. C. Baley, Analysis of the flax fibres tensile behaviour and analysis of the tensile stiffness increase, Composites Part A. 33 (2002) 939-948.

21. S. Eichhorn, R. Young, Composite micromechanics of hemp fibres and epoxy resin microdroplets, Comp. Sci. Technol. 64 (2004) 767-772.

22. K. Goda, M.S. Sreekala, A. Gomes, T. Kaji, J. Ohgi, Improvement of Plant Based Natural Fibers for Toughening Green Composites – Effect of Load Application During Mercerization of Ramie Fibers, Composites Part A. 37 (2006) 2213-2220.

23. H. Hargitai, I. Ráez, R.D. Anandjiwala, Development of hemp fibre reinforced polypropylene composites, J. Thermoplastic Comp. Mater. 21 (2008) 165-174.

24. P. Wambua, J. Ivens, I. Verpoest, Natural fibres: can they replace glass in fibre reinforced plastics?, Comp. Sci. Technol. 63 (2003) 1259-1264.