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Publisher's version / Version de l'éditeur:

238th ACS National Meeting [Proceedings], 2009-08-16

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Tensile Property Characterization of Natural Fibres Applying Single Fibre Tensile Test

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1. INTRODUCTION

Natural fibres such as flax, hemp, sisal, possess the advantages of good mechanical properties, renewability, environmental friendliness and also economical feasibility. Therefore they have been receiving more attention for the past two decades as reinforcements for polymer matrix composites [1]. Accurate and reliable measurement of the tensile strength of natural fibres by feasible technique thus becomes crucial for the comparison between different kind of natural fibres and also for the prediction of mechanical property of their composites. Single fibre tensile test (SFTT) is the most widely applied method for the measurement of the tensile properties of fibres [2-5]. While this method provides acceptable strength and modulus for synthetic fibres, it fails to provide accurate results with low standard deviation (SD) for natural fibres. In this paper, a new approach to measure the tensile properties of natural fibre was described. Flax bast fibre was used to validate the method and the results of the measurements are reported.

2. IMPROVED SFTT METHOD FOR NATURAL FIBRES

SFTT was first developed to determine the tensile properties of synthetic fibres. In this method, the calculation of fibre cross-section area is done assuming that the fibre is considered perfectly round, which is true for most synthetic fibres. Optical microscopy (OM) is commonly used to determine the fibre diameter before testing. From the force at which a single fibre fails under the tensile test, the tensile strength of a single fibre can be easily obtained. The conventional SFTT provides good and reliable tensile properties for synthetic fibres.

However, natural fibres are quite different from synthetic fibres. Natural technical fibre often consists of a bundle of elementary fibres, which results in an irregular shape depending on the number of elementary fibres and the way which they are packed together. Fig. 1 presents a typical OM image of the morphology of the seed oil flax fibres, showing cross-sections of both technical and elementary fibres. In addition, the cross-section of elementary fibre is not perfectly round, either. Thus, the fibre diameter observed under OM can vary a lot depending on the view it is observed. Furthermore, due to its irregular shape and its non-uniformity along the fibre axis, it is difficult to obtain a good focus on the fibre image under OM to determine fibre diameter.

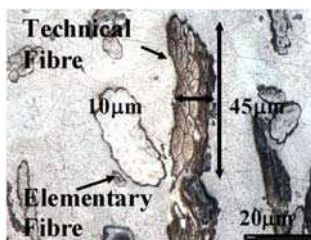


Figure 1. OM image of fibre cross-section.

The improved SFTT involves modifications of the SFTT which are described below. These modifications focus on: 1) the selection of fibres for testing and 2) the accuracy of cross-section area determination of natural fibres.

2.1. Sample Selection for Testing. Firstly, single technical flax fibres without splitting were carefully selected by hand then by OM. Fibres with apparent defects should also be removed in this process if such defects are not representative for the fibre nature. In addition, contaminated fibres would result in an obscured cross-section image

thus introducing error on the determination of cross-section area. They should be removed, too.

2.2. Fibre Tensile Testing Procedure. The pre-selected fibres are tested on a standard mechanical testing system at a desired temperature and condition.

2.3. Cross-section Area Determination. In order to determine tensile strength and modulus of the fibres, the accurate cross-section area must be obtained. Since fibre failure is very brittle and its elongation at break is very low (far less than 2%), it can be considered that the cross-section area of the fibre at the failure location does not change significantly after failure. After testing, fractured fibres with appropriate fracture end were selected for the cross-section area calculation. Selection of fracture end was done by microscopical observations to discard fracture end that split into fibril fibres and keep brittle fracture end without splitting for the further cross-section area determination.

In order to improve the accuracy of the calculation of cross-section area, it is important to obtain a flat and clear cross-section of fibre fracture end. Therefore, the tested fibre was carefully attached on a tape, perpendicularly to the edge of the tape. OM coupled with Visilog 5.4 software was utilized to determine the distance between the edge of fibre fracture end and tape, thus to determine the optimum location at which the samples should be cut in order to provide a good presentation of the cross-section and also a clear image for the determination of cross-section area in the later step. To prevent the further movement of the fibre, it was fixed between 2 strong polyethylene (PE) films (as supporting film). The edge of tape with fracture end and PE films end were tried to be placed on the same plane. A scheme of such arrangement is shown in Fig. 2 (a). The size of the PE films had to be fit to the mould. Then the sample was mounted with epoxy resin using the mixture of Epofix resin and Epofix hardener (Struers Company) at room temperature for 24 h. The scheme of such layout is given in Fig. 2 (b).

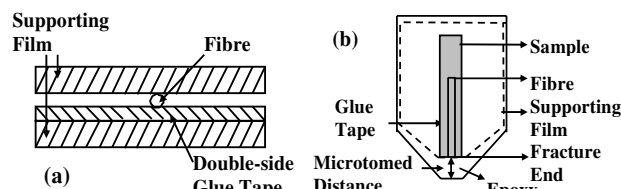


Figure 2. (a) The cross-section of the tip of the sample; (b) the layout of the sample molded in epoxy mould.

The embedded sample was finally microtomed according to the distance measured earlier by OM between the edge of tape and the fracture fibre end. More than one cut should be performed to ensure a good representation for the cross-section as necessary. Scanning Electron Microscope (SEM) was used to get cross-section image of fibre fracture end (Fig. 3 (a)) with high accuracy after the sample was coated by Au / Pd. From the SEM image the borderline of the cross-section was traced out using the Adobe Photoshop 4.0 LE software carefully. Fig. 3 (b) shows the corresponding boundary line obtained from Fig. 3 (a). Finally, the accurate value of total cross-section area could be obtained automatically using Image-pro Plus 4.5.1.27 software according to the borderline.

2.4. Calculating Tensile Strength and Modulus. As the cross-section area of the fibre is determined and its corresponding force-elongation is obtained from the test, the tensile properties of the fibre can be easily evaluated according to the ASTM D 3822-01.

3. EXPERIMENTAL

Bast flax fiber (F1) used in this study was kindly supplied by Schweitzer-Mauduit Company. A tensile machine Instron 5548 Microtester was used for tensile tests. Bausch & LOMB Optical Microscopy coupled with a COHU high performance color CCD camera was utilized in the improved method for fibre selection. It was also used to help determine the cutting size in the cutting procedure, and fibre diameter with the aid of Visilog 5.4 software during conventional SFTT. A Reichert-Jung 2050 Supercut Microtome was used in the cutting

procedure. JEOL JSM-6100 SEM working at a voltage of 10kV was utilized to select the good fracture end and determine the cross-section area with the aid of Image-pro Plus software.

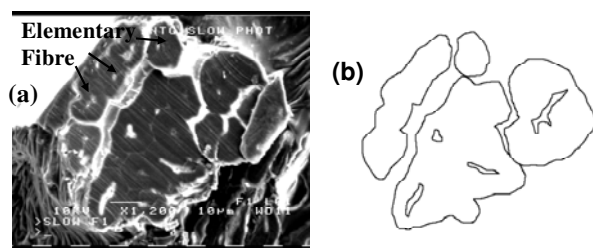


Figure 3. (a) SEM image of flat cross-section image after cutting procedure; (b) the boundary line of cross-section in (a) traced out using Adobe Photoshop 4.0 LE software.

The following SFTT were conducted according to ASTM D 3822-01 at room temperature. Tensile tests were performed on the selected flax fibres (2.7). In this work, a grip length of 9 mm and a gauge length of 50 mm were used for testing. A translation speed of 120 mm / min was applied in all the tests.

The conventional method of diameter measurement for the calculation of cross-section area was carried out in comparison with the improved method on the selected samples. The diameter of 20 specimens was determined under OM before testing. The average fibre diameter at five different random locations on the fibre was applied to determine the diameter of fibre. The obtained diameter, D, value was utilized to calculate the cross-section area using equation of $area = \pi D^2 / 4$ for the final mechanical data analysis. The improved SFTT test was conducted on the selected flax fibres using the procedure described in 2.. Six specimens with good fracture end were assumed to be fair enough to determine the tensile property of fibres.

4. RESULTS AND DISCUSSION

Excluding some slippage in the typical stress - strain curves (not shown here) of the F1 fibre from the tensile test at the beginning of the test, all tested flax fibres exhibited a linear elastic deformation until failure, and very brittle failure behavior with minimum deformation of less than 2%.

4.1. Conventional SFTT. The average diameters, tensile strengths, modulus and strains of the F1 fibres including the SD values calculated from 20 specimens applying the conventional SFTT could be found in Table 1. It has been reported that the tensile strength and modulus of flax fibres are within the range of 345-1035 MPa and 27.6-80 GPa, respectively [1,6]. The reason for the lower strength value of F1 here was possibly due to the oilseed type as well as growing area, climate factors and retting conditions. It was noticed that the SD in average diameter for a single fibre specimen was very high and over 40%, although specimens were carefully chosen for the test to limit effects of fibre non-uniformity and defects on results, and a large number of specimens were used aiming to reduce the SDs. The problem should be mainly due to the poor approach of fibre cross-section determination. As diameter is proportional to the strength and modulus in a factor of power of 2, a large error in diameter must lead to a great SD in strength and modulus. The OM image of the technical flax fibres F1 in Fig. 1 illustrates the irregular shape of flax fibre, by which the OM observation of diameter could produce greatly different values depending on what angle the fibre was observed. As seen in one typical fibre in Fig. 1, the maximum diameter value could be as large as 45 μm , while the minimum value could be as small as 10 μm . Thus could lead to very different values of strength and modulus by about 20 times as for this specific fibre.

4.2. Improved SFTT. Since fibre fracture is a brittle mode in the test and fibre strain at break is limited to 2%, it can be assumed that the cross-section area after break does not significantly differ from that before fracture. Therefore, fibre cross-section area at the fracture location can be determined after the test. However, in some cases, due to the hollow structure of elementary fibres and the brittle nature of

natural fibre, the fibre boundary can be deformed or split after mechanical test. Thus it is too difficult to identify the boundary of the fibres. As a consequence, preparation of the fibre fracture end for observation as previously described is important. Because the elementary fibres are uniform along the fibre axis for a certain range (counting from the fracture end), it is expected that the cutting will not contribute significant error on the cross-section area determination. The good microtomy can provide a clear flat cross-section image of fibre fracture end, as shown in Fig. 3 (a). The fibre cross-section area is the sum of the cross-section areas of all elementary fibres consisted in the tested technical fibre and the voids in the center of the elementary fibre was also taken into account. The high magnification and resolution of SEM coupled with image analysis could enhance greatly the precision. As clearly seen, this method provides a most improved fibre cross-section area determination for the SFTT.

Table 1. Diameter, Tensile Strength, Modulus And Strain Values With SD Values Of Flax Fibres Obtained from Conventional SFTT Method and Improved SFTT Method

		Conventional SFTT						
F1	Diameter (μm)	SD (μm)	Strength (MPa)	SD (MPa)	Modulus (GPa)	SD (GPa)	Strain (%)	SD (%)
	99	34	205	87	48	29	3.7	0.94
		Improved SFTT						
F1	42.6	6.7	400.6	40.8	48.2	4.9	2.0	0.84

Table 1 comparably shows the equivalent diameter, tensile strength, modulus and strain, and their SD values of F1 obtained from the improved method. The strength from the improved SFTT failed in the lower range of those reported in [1,6]. One significant result is SDs. Although only 6 specimens were tested in this new method (while at least 20 specimens for the old methods), it provides sufficiently lower SDs, which is less than 11%. These SD values were also much lower than those in the literatures [2-5], where the conventional method was applied for the calculation of tensile strength of natural fibres.

5. CONCLUSION

An improved SFTT method to obtain more precise tensile strength and modulus of natural fibres was developed. This is based on the fine selection of the tensile tested fibres and on the direct cross-section area measurement at the failure location. A more reasonable number of samples (around 6) needs to be tested to obtain reproducible results. Applying this new approach, the accurate tensile strength of bast flax was measured to be 400.6 ± 40.8 MPa, with the low SD of less than 11%. While tensile strength of these fibres determined by the conventional SFTT method presented SD of over 40%.

ACKNOWLEDGEMENTS

The authors acknowledge the Agriculture-Agri-food Canada for the funding via ABIP and NBP program and also the Biotechnology Research Institute of the National Research Council Canada and Schweitzer-Mauduit Canada for providing flax samples. Hu Wei thanks to the National Science and Engineering Research Council Canada for granting her a Postdoctoral Fellowship.

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