MECHANICAL PROPERTIES OF UNIDIRECTIONAL EPOXY MATRIX COMPOSITES REINFORCED WITH SCUTCHED FLAX AND TOW BY-PRODUCT

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Abstract

The decortication of flax by scutching yields scutched flax and tows.
In this study, we have compared the properties of composite materials made of scutched flax and flax tows from the same batch. A series of unidirectional epoxy composites were manufactured by wet moulding. Mechanical properties of single fibers and composite materials were measured by tensile tests. The tensile properties of single fibers were in the same range. The tensile properties of the unidirectional composites show a similar evolution of properties versus fiber volume fraction. The results show that tows could be used to reinforce high performance composite materials.

1. Introduction

A wide range of plant fibers have been studied for composite reinforcement including hemp, jute, sisal and flax [1]. Among them, flax fibers have excellent specific mechanical properties and are being evaluated as a replacement for E-glass fibers [2,3]. Flax (Linum usitatissimum) is the major plant fiber cultivated in northern Europe, mainly for the textile sector. The structure and composition of flax plants is complex [4,5]. The stems contain fiber bundles embedded in cortex tissues at the periphery. In these bundles, single fibers are grouped together by middle lamellae. The latter consist of pectic cements. A woody core is located in the middle of the stem.

The production of flax includes the cultivation of the plant, retting and decortication of the straw to extract the raw fibers. After growing and when the maturity is reached, flax stems are pulled from the ground and laid on the field to allow dew retting. Damp and warm weather lead to the colonization by fungi and bacteria which release several enzymes [6]. The epidermis, cortical tissues and middle lamellae are degraded which free the bast fiber bundles [4,7]. This facilitates the subsequent decortication process [8]. Scutching is the regular decortication process used to separate the bast fibers from the woody core [9,10]. This process yields two fibrous products: scutched flax and tows. Scutched flax is made of aligned long flax fibers containing a small amount of shives. Tows are made of entangled flax fibers and contain a large quantity of shives. Tows result from the mechanical action of scutching, when shives are scrapped out from the straw.

Scutched fibers have the highest value of all flax products. Scutched flax can be directly hackled to be used for yarn spinning. Tows have less value as they must undergo further opening and carding operations to be cleaned of shives and aligned prior to spinning. In March 2014, the market price of scutched flax and tows were respectively 1.7 €/kg and 0.7 €/kg.
Andersons et al. (2009) compared the tensile properties of unitary flax fibers from tows and scutched flax. Their study showed that the strength of tow single fibers (860 ± 330 MPa) was higher than that of of scutched flax single fibers (660 ± 330 MPa). This is a surprising result which requires further explanation.
Van de Weyenberg et al. (2003) studied the mechanical properties of epoxy/flax UD composites reinforced with different products and processing. Their study showed that materials made of carded tows had better strength at break than scutched flax, but had a lower stiffness caused by the much shorter fiber lengths in these bundles.
More data on mechanical properties are needed in order to evaluate the potential of tow fibers for composite reinforcement.
In this study, we have compared the mechanical properties of scutched flax and tow. The tensile properties of single fibers were measured first, then the tensile properties of UD flax/epoxy composites were measured.

2. Experimental section

2.1. Tensile test of single fibers

Single fibers originating from scutched fibers and tows were hand selected in the central zone of the stem and bonded onto a paper frame with a gauge length of 10 mm. Single fiber apparent diameter was measured at three points along the fiber to calculate cross section area. Tensile tests were performed on a MTS Synergie RT/1000 machine equipped with a 2N load cell. The test speed was 1 $mm.min^{-1}$.Tensile tests were carried out at controlled temperature (23 °C) and humidity (50%). Single flax fibers exhibit a nonlinear tensile behavior, so the apparent tensile modulus was measured by calculating the slope of the curve in the last linear part [2]. Calculated values of tensile modulus and failure strain take into account a correction for the compliance of the test machine. Around 60 fibers were tested for each condition. The results were analyzed statistically using the Student's t test.

2.2. UD Composites manufacturing

Fiber bundle samples cut to a length of 10 cm were wet impregnated with epoxy and inserted into an aluminum rail. A second rail was placed on top of the mixture and pressure was applied to obtain the desired thickness. The pressure was maintained during hardening. After room temperature cure (23°C-24h), samples were post cured following the supplier's recommendation (40°C, 3h ; 60°C, 2h ; 80°C, 2h ; 100°C, 4h). Glass/epoxy tabs (±45°) were bonded on tensile specimen ends with an Araldite 2011 (Huntsman) adhesive and cured (23°C, 24h ; 50°C, 12h) before composite testing.

2.3. Longitudinal tensile test of composites

Tensile tests were performed on the tensile specimens described in section 2.2. An Instron 5566 tensile machine was used. The capacity of the load cell was 10 kN and a 25 mm nominal length extensometer was used. The crosshead displacement speed was 1 $mm.min^{-1}$. The tensile modulus was obtained by calculating the slope of the tensile curve in the second linear part of the curve after a strain of 0.5 %.

3. Results and discussions

3.1. Tensile properties of the single fibers

The tensile properties of single flax fibers were measured for tows and scutched fibers. The values of tensile modulus, strength and strain at break are reported in Table 1. The mean tensile modulus of tow fibers (51 ± 16 GPa) was slightly higher than for scutched fibers (47 ± 16), while tensile strength of scutched fibers (937 ± 400) was slightly higher than that of tow fibers (870 ± 342). Strain at break of scutched fibers (2.0 ± 0.6) was higher than the strain at break of tow fibers (1.8 ± 0.5), which is consistent with the strength difference.

Material	**E (GPa)**	**σ (MPa)**	**A (%)**
Scutched flax	47 ± 16	937 ± 400	2,0 ± 0,6
Flax tows	51 ± 16	870 ± 342	1,8 ± 0,5

Table 1. Tensile properties of the single fibers

Our results show similar values for the two types of fibers considering the scatter of data. Statistical Student's t-tests were carried out and showed that values of tensile modulus, strength at break and strain at break were not significantly different ($p>0.05$).
The tensile properties of single fibers studied in this work are in the range of previously reported tensile properties for flax fibers under the same test conditions [11–13].
Our results show that single flax fibers originating from tow bundles and scutched flax bundles have similar tensile properties despite differences due to the decortication process.
This shows that tows are not weak fiber bundles. This could also indicate that scutched bundles and tows come from the same part of the plant. Based on these results both scutched fibers and tow fibers can be considered as high performance materials in terms of single fiber tensile properties even if the latter is entangled and contains shives.

3.2. Tensile properties of the composite materials

A series of unidirectional composites materials tensile specimens was manufactured for both scutched and tow fiber bundles. 21 and 24 tensile specimens were manufactured respectively with scutched and tow bundles.

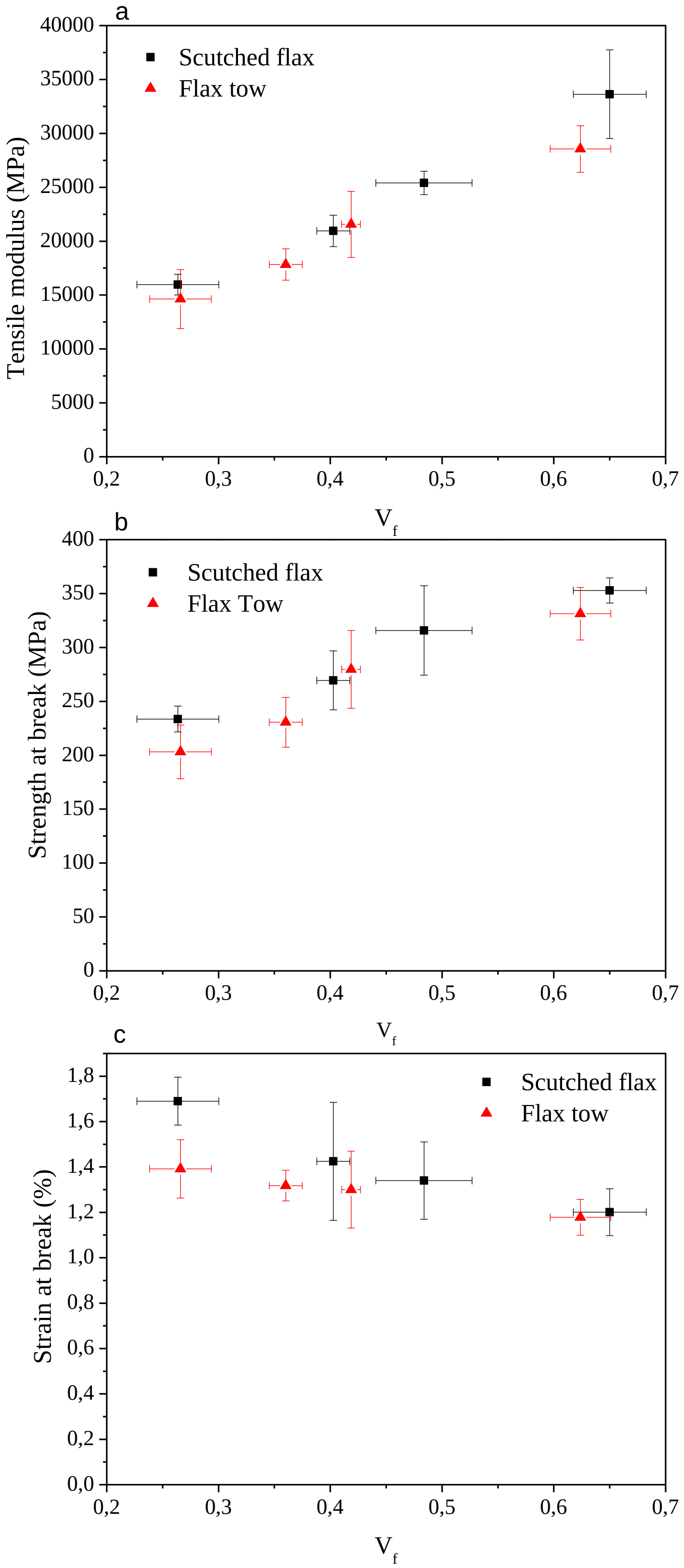

Figure 1. Average tensile properties of flax/epoxy UD composites reinforced with scutched flax (□) and tows (Δ) a) Tensile modulus b) Strength at break c) Strain at break

Figure 1 a), b) and c) shows the average measured values of tensile modulus, strength at break and strain at break as a function of fiber volume fraction for the flax/epoxy UD composites made of scutched flax and tow bundles. Tensile modulus and strength at break increase and the strain at break decreases with the volume fraction of fiber.
The tensile properties exhibit similar trends for both types of product. This means that tows or scutched bundles can give UD composites of equal longitudinal stiffness and strength. This result is consistent with the equivalent tensile properties of the single fibers shown in section 3.1. However, the maximum volume fraction achieved was lower for composite reinforced with flax tow.
In summary, measured composite tensile property values are similar for both scutched flax and tow flax composites.

Conclusion

During the industrial production of flax, the decortication process yields one main product, scutched flax, and a fibrous by-product, flax tows. The tensile properties of single flax fibers and the tensile properties of epoxy/flax UD composites have been investigated for the two products.
Tensile properties of single fibers originating from scutched flax and flax tows were not significantly different. The tensile characterization of epoxy/flax UD composites showed that the tensile properties of composites made of scutched flax or tows are in the same range.
It was shown here that flax tow bundles are made of high performance single fibers. The composite tensile properties were not lowered when reinforced with flax tow bundles.
The use of tows would allow the development of high performance reinforcements at lower economic and environmental cost.

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