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Image analysis for the quantification of dislocations in hemp fibres

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Abstract

When a natural fibre is subjected to compression stress in the longitudinal direction, local misalignments of cellulose microfibrils, so-called dislocations, may form in the cell wall. For most uses, dislocations have a negative influence on the performance of fibre-based products, and a means of characterising fibre resources with regard to dislocations would be valuable. In the present study, we have developed a procedure for semi-automatic quantification of the amount of dislocations in elementary hemp fibres. The procedure is based on polarised light microscopy and simple image analysis tools. Results from a similar approach have been published earlier by others, but no details of the method used were reported. In the present study, the relative dislocation area is determined from two digital images captured using polarised light microscopy. One image is optimised for the detection of the fibre edge, the other is optimised for the detection of dislocations. The area of the dislocations (obtained from the second image) relative to the total fibre area (obtained from the first image) gives a figure that expresses the relative dislocation area. The method is sensitive to the light intensity of the microscope and to the angle between the longitudinal direction of the fibre and the vibration direction of the polariser. It follows from this that strict standardisation is important if results from different fibres are to be compared.

Keywords: Dislocations; Fibres; Hemp (*Cannabis sativa* L.); Image analysis; Polarised light microscopy

1. Introduction

Dislocations are local misalignments of cellulose microfibrils in the cell wall of natural fibres such as wood, flax and hemp. Depending on the severity of the deformation and on the context, such zones have also been called nodes, kinks, kink bands, slip planes, misaligned zones or microcompressions. In this presentation the term “dislocations” is chosen in accordance with the review by Nyholm et al. (2001). Cellulose crystal chains of microfibrils in dislocations have a different orientation than those of the undisturbed cell wall. This is why dislocations may be revealed by polarised light microscopy.

1.1. The origin of dislocations

Dislocations are formed as a result of subjecting a fibre to compression stress in the longitudinal direction (Robinson, 1920), and it appears that dislocations very often occur already in the living plant due to for

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example wind load or growth stress. However, several studies have shown that dislocations are easily introduced into wood samples during the preparation of slides for microscopy (for example Hartler, 1969 and Hoffmeyer, 1990), so the results from earlier studies on the amount of dislocations in living trees should be interpreted with care. For pulp wood, a number of publications have shown that the process of isolating the fibres from the stems as well as other steps during pulping give rise to new dislocations and/or to the enhancement of those already present (Nyholm et al., 2001 and references therein).

1.2. Dislocations and fibre performance

When natural fibres are used as reinforcement in composites, the interphase between the matrix and the fibres shows stress concentrations adjacent to dislocations (hemp–epoxy composites studied by Hughes et al., 2000), indicating that these zones may lead to crack initiation and/or debonding between matrix and fibre. In another study, Davies and Bruce (1998) found a negative correlation between the tensile strength of flax and nettle fibres and the extent of dislocations in the fibres. Bos et al. (2002) reported that the tensile strength of elementary flax fibres isolated by hand was 1834 ± 900 MPa, while it was 1522 ± 400 MPa for scutched and hackled fibres. The fibres isolated by hand were reportedly "virtually free of kink bands". Based on observations of 63 spruce latewood fibres constrained by a vinylester matrix, Ljungqvist et al. (2002) used Weibull statistics to calculate that the strain to failure was approximately 12% larger for a theoretical 0.1 mm long fibre without visible dislocations than for a corresponding fibre with 70 dislocations per millimetre.

A number of studies have shown that dislocations negatively influence the properties of chemical pulp (for example Terziev et al., 2003 and references given by Nyholm et al., 2001). However, the relationship between dislocations and pulp properties is not black-and-white, and not yet fully understood. It appears that the effects of the dislocations on the pulp properties are related to the stage of the pulping process at which dislocations are induced (Hartler, 1969; Hakanen and Hartler, 1995; Ander et al., 2003), and that the severity of the effects are confounded with the type of pulping process (sulfite/sulfate, Hartler, 1969). Hartler (1969) and Hakanen and Hartler (1995) stated that dislocations only constitute weak locations if they are exposed to high temperature in alkaline or acidic medium, i.e. only if lignin is removed after the dislocation was created. Contrary to this, Kibblewhite (1974) and Kibblewhite and Brookes (1975) concluded that the wet strength of kraft pulps could be increased if the fibres were kinked before bleaching. The relationship between dislocations and pulp properties is presently being studied by Ander and co-workers (Swedish Agricultural University, Uppsala, Sweden).

The studies mentioned above indicate that the amount of dislocations could be an important characteristic of natural fibres and serve as a potential parameter when evaluating the quality of different fibre resources or when evaluating the damaging effect of a specific step in the production process, no matter whether the end product is a fibre composite or a sheet of paper. It could also help illuminate the role of dislocations in the pulping process. In spite of this, documented attempts to develop an automatic or semi-automatic method for the quantification of dislocations in fibre resources are scarce.

1.3. Polarised light microscopy

In almost all studies published hitherto, visualisation of dislocations is achieved by use of a polarising light microscope, i.e. a light microscope equipped with devices capable of producing and detecting plane polarised light (Preston, 1974). Between the light source and the sample stage the light is plane polarised using a plate called a polariser. Between the sample stage and the eyepieces, the analyzer, i.e. a second identical plate is inserted. The plates are normally polaroids. They are sometimes called polars or Nicols. If the polariser and/or the analyzer are rotated so that their vibration directions are perpendicular to each other, the set-up is denoted crossed polars. When plane polarised light passes through a birefringent material at a direction normal to the surface, the light will split into two components vibrating in two perpendicular planes, and the two components will travel through the material at two different speeds (a slow and a fast component). When a birefringent material such as crystalline cellulose is rotated under crossed polars, it will disappear (become dark) when one of the two vibration direc-