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Scenarios of crack propagation in bast fibers: Combining experimental and finite element approaches

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ABSTRACT

This work investigates the rupture of bast fiber type from hemp, to attain better control over the ultimate tensile and fracture strength properties of hemp composites. Crack propagation in both individualized and bundles of hemp fibers is studied. Crack initiation is controlled using generated defects within fibers. A non-contact-ablation apparatus creates these defects using a laser beam directed by high-precision optics. V- and U-type notches are processed, with sizes ranging from 2 to 30 μm in depth. The micromechanical testing of damaged fibers is coupled to a high-speed camera, allowing for the measurement of ultimate properties as well as monitoring of the crack propagation.

Finite element simulation is developed to identify possible damage scenarios for bundles and elementary fibers. Microcracks are allowed to initiate, grow and coalesce based on non-prescribed crack propagation (i.e., not imposed or with direction update) and stress criteria. High speed camera recording indicate a wide variability in crack propagation speed in the range 2–149 m/s. Both longitudinal and transverse cracking are observed depending on the notch geometry. Our results demonstrate that the damage kinetics is a combination of growth and coalescence of microcracks. These damage mechanisms compete depending on the notch geometry and fiber element dimensions.

1. Introduction

Fibers from synthetic or natural origin are widely used in structural materials as a reinforcing filler because of their beneficial strength and stiffness [1]. In addition, the fiber structure and arrangement possibilities provide a key advantage over other reinforcing materials to create controlled anisotropy [2], which allows more flexibility when tailoring the properties of structural materials. Another interesting geometrical property of the fiber is its ability to percolate rapidly when mixed with a second phase at small content levels [3].

In various engineering situations, fibers also act as damage traps to avoid the instable failure of composites via mechanisms of fiber bridging or interfacial debonding [4,5]. Damage tolerance and specific rupture properties of the fiber are to be related to its substructure [6]. Therefore, the study of the fracture properties of fibers is of utmost importance. Failure control of structured materials should be achieved by a better understanding of the failure mechanisms in fibers elements (bundles or individualized fiber).

When referring to natural fibers, all issues faced with synthetic fibers are also a concern. A typical example is the structural anisotropy induced by Jute fibers in polymeric composites as reported by Cichocki and Thomason [7].

Fracture is defect sensitive in natural fibers because defects are genuine characteristics of raw natural fibers [8]. Their presence can be attenuated, for example, by accepting chemical treatment to achieve a better surface state [9]. The role of defects on the fracture properties of scattered fibers is as substantial as that of the intimate fiber architecture. For instance, mechanical parameters have been reported to depend on the fiber dimensions, crystallinity, phase content and arrangement (fibril angle) and on various defects, such as kink bands, crimps, curls and surface microcracks [6,8,10]. The shape-dependent fracture properties should be analyzed in terms of rupture mechanisms that expose crack departure from internal or surface flaws. Weibull statistics performed on tensile strength results indicate that the tensile strength is positively correlated with the fiber diameter, which provides additional evidence of the increasing surface effect in such materials.

Giving the large propagation speed achievable by one or more cracks and giving the varieties of micro-crack sites and also difficulties to observe damage phenomena within large time and size

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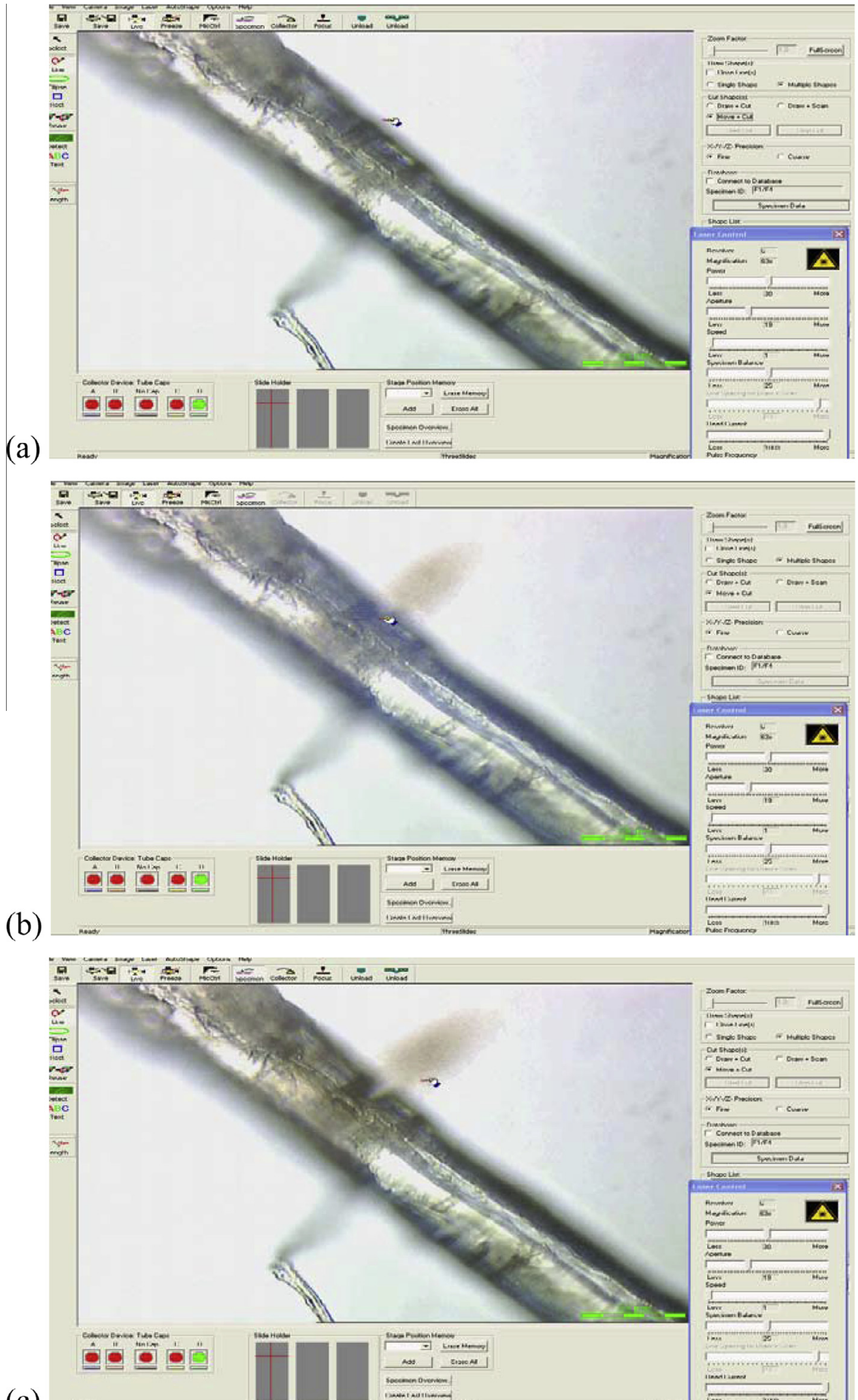

Fig. 1. Interactive process of laser micro-dissection used to process V- and U-shaped notches in hemp fibers and bundles.

frames, the tensile rupture can be efficiently studied only by controlling the defect size and shape. In the present work, we use a laser ablation process to create notches in hemp fibers that sufficiently concentrate stress during loading to enable better control of the rupture process. To the best of our knowledge, this process control approach has never been attempted.

Even if control of the defect size is achieved, this control only ensures that the initial position for fracture departure is predictable, not the entire process of crack propagation. For a clear description of the failure process, we need to introduce a possible scenario of damage evolution that explains how damage evolves within the fiber. In this work, this task is achieved by implementing a finite element model that combines damage and crack propagation. This model is applied to study the failure of hemp bundles and elementary fibers by considering the defect characteristics and fiber geometry. Hemp fibers are natural fibers and, in particular,