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Hygromechanical characterization of sunflower stems

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ABSTRACT

This study concerns the determination of hygromechanical properties of sunflower stems. Mechanical tests were carried out on specimens of sunflower bark and pith. Particular attention was paid to the influence on the mechanical properties of (i) specimen location along the stem and (ii) moisture content of specimens. For this purpose, specimens were taken from the bottom, middle, and top of the stems. The influence of humidity on the mechanical properties was studied by testing specimens conditioned at three different relative humidities: 0% RH, 33% RH and 75% RH. Moisture diffusion coefficients of bark and pith were deduced assuming Fick's law to predict the variation in moisture content of the specimens during the mechanical test. The Young's modulus of the bark was found to be higher than that of the pith, whereas the moisture diffusion coefficient of the bark was lower than that of the pith. Mechanical and hygroscopic properties of specimens depended on their location along the stem. In order to explain these results, morphological observations have been carried out on the specimen at each location. It was found that porosity of both the bark and the pith are lower at the top of the stem. The presence of sclerenchyma in the bark is also higher at the top of the stem.

1. Introduction

Green industry is important both economically and environmentally. Research on the development of new bio-sourced materials has thus been attracting more and more attention. During the last decades, bio-composites reinforced by plant fibers such as wood, flax, hemp, jute and sisal have been rapidly developed for various industrial applications such as structural components for the automotive and building industries (Mohanty et al., 2005). Compared with conventional synthetic fibers, natural fibers offer some advantages including cheapness, low density and biodegradability, but their mechanical properties are generally inferior.

Besides industrial crop activity solely devoted to fiber production, another potential source of natural fiber supply is agricultural by-products, especially for industrial applications in which required mechanical performance is not too high. Against a rapid expansion of natural fiber-based composites, new composites reinforced with agriculture by-product fibers offer a potentially effective way to ease disparities in natural fiber supply and demand. The cellulose content of most agricultural by-product fibers is generally lower than that of traditional natural fibers such as wood, flax, hemp, jute or sisal. Cellulose content directly influences mechanical properties. This drawback can, however, be offset by cheapness in many industrial applications. Some studies on the use of agricultural by-products as composite reinforcement are reported in the literature. They concern corn stalk, and wheat, rice or corn straw (Ardanuy et al., 2011; Ashori and Nourbakhsh, 2010; Nourbakhsh and Ashori, 2010; Panthapulakkal et al., 2006; Wang and Sun, 2002; White and Ansell, 1983; Yang et al., 2003). These studies clearly show that such by-products offer a relevant, promising solution for some composite applications. The even trade-off between cheapness, mechanical properties, abundance and availability of these agricultural by-products makes it possible to use them in industrial applications. Aside from these advantages, using agricultural by-products can also improve the agriculture-based economy and create new market opportunities.

This study concerns the characterization of hygromechanical properties of sunflower stems, an abundant agricultural by-product. These stems are generally shredded during flower harvesting and used as natural fertilizer. In Europe, sunflower is cultivated for the edible oil extracted from its grains: it is one of the three main sources of edible oil along with rapeseed and olive. This plant is thus widely cultivated. In 2010, the harvested area in Europe was 3.68E+06 ha, 16% of the total harvested area in the world (FAOSTAT Statistical Database). The flower itself is clearly the most useful part of the plant; there is no significant industrial use of the stems shredded after flower harvesting. These stems may,

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however, exhibit favorable mechanical properties (of the bark) and good heat insulation properties (of the pith). Hence this by-product could find use in bio-sourced composite materials.

The aim of this study was to investigate the mechanical properties of the bark and pith of sunflower stems. Our purpose was to collect information that would be useful for designing bio-composite panels suitable for building insulation (see DEMETHER Project). Such panels must feature both useful heat insulation properties and mechanical properties sufficient to ensure safe handling, transport and assembly. The properties of the bark and the pith directly influence the properties of the panels. It is clear that the pith of the stem shows good insulation properties while the bark shows good mechanical properties. The mechanical responses of both the pith and bark have therefore to be assessed for predicting and modeling the global response of the panels and find a trade-off between heat insulation and mechanical properties.

In what follows, the specimens, tests and testing procedures are first described. Results obtained with hygroscopic and mechanical tests performed on bark and pith of sunflower stems are then presented and discussed, with special emphasis on the influence of the moisture and sampling zones on the results obtained.

2. Materials and methods

2.1. Specimens, locations and preparation

2.1.1. Introduction

The sunflower species used for this study was LG5474, grown in Perrier, France, in 2010. A separate mechanical characterization was justified by the fact that the appearance of the bark and pith, and their hygromechanical properties, were very different. Specimens used in this study were extracted from portions of stems of length 765 mm. For all the stems from which specimens were cut, the bottom section was chosen at the level of the first node above the roots. The location of this first node did not significantly change from one stem to another. Three sampling zones were chosen to investigate the effect of specimen location on hygromechanical properties. The first sampling zone was located at the bottom of each stem, the second at the middle and the third at the top (see Fig. 1). These short portions of stem were then used to cut either bark or pith specimens, but not both at the same time, because cutting bark specimens damages pith and *vice versa*.

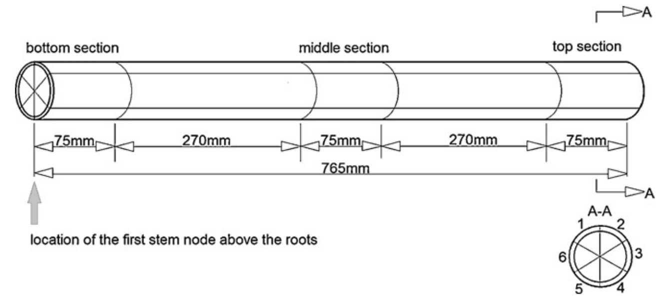

Fig. 1. Sampling zones.

2.1.2. Bark specimens

For bark specimens, the short portions of stems were divided lengthwise into six parts (see cross section A-A in Fig. 1). Bark specimens extracted from the same angular location were noted with the same number (from 1 to 6). The geometry of the specimens was the same for the mechanical and for the hygroscopic tests (see Fig. 2(a)) as regards dimensions and inner and outer surfaces of the bark specimens. To obtain nearly plane specimens and to remove some pith residues, the inner face of the bark was lightly polished with sandpaper. The outer face was not polished, because some stiff fibers (sclerenchyma) are located around the stems; polishing the outer surface would have damaged them, thereby influencing the mechanical properties. These fibers and other stem components are clearly visible in Fig. 3 (Tiftickjian, 2012), where a typical cross section of sunflower stem is depicted.

For the hygroscopic tests, six specimens cut from two stems were tested for each of the three sections (bottom, middle and top). Three non-adjacent specimens were chosen from each section, for example specimens 1, 3 and 5 (see Fig. 1). Only three specimens were chosen per section and per stem (and not the whole set of six), because preparing the specimens was time-consuming and intricate. The number of specimens was therefore limited. All these specimens then underwent two different absorption/desorption tests: the specimens were first dried in an oven (see description below) and then exposed to two different levels of relative humidity

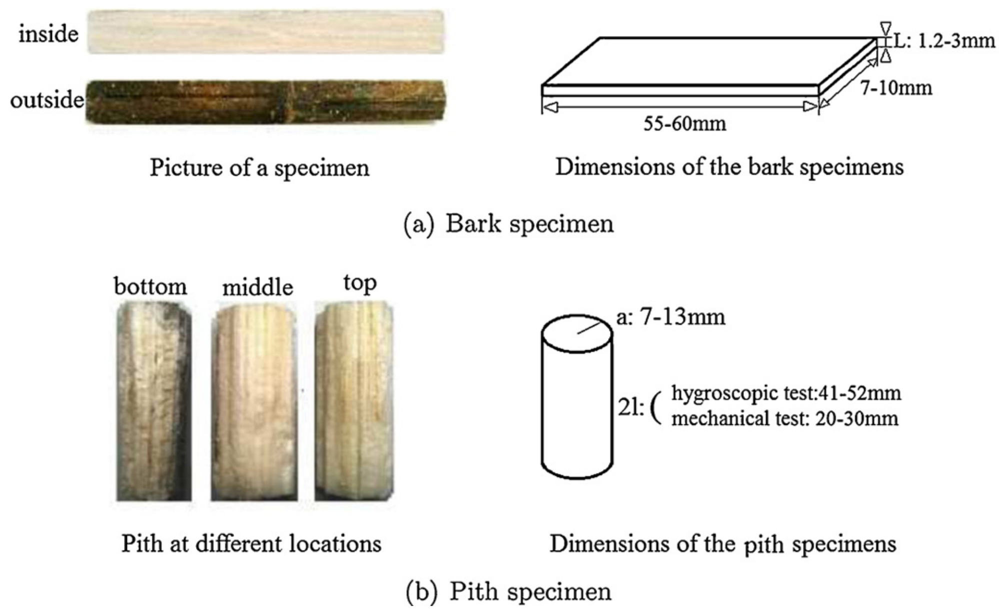

Fig. 2. Bark and pith specimens.