MECHANICAL BEHAVIOR OF BARK OF SUNFLOWER STEM FOR BIO-COMPOSITE APPLICATIONS

S. Sun[1, 2], J. D. Mathias[3]*, E. Toussaint[1, 2], M. Grédiac[1, 2]

[1]*Clermont Université, Université Blaise Pascal, BP 10448 F-63000 Clermont-Ferrand France*
[2]*Institut Pascal, Puy-de-Dôme, CNRS, UMR6602, 63177 Aubière Cedex France*
[3]*IRSTEA, Laboratoire de l'Ingénierie pour les Systèmes Complexes, Puy-de-Dôme, Campus des Cézeaux, 24, avenue des Landais, BP 50085 F-63000 Clermont-Ferrand France, 63172 Aubière Cedex France*
**e-mail address of the corresponding author: jean-denis.mathias@irstea.fr*

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Abstract
This work consists in determining the mechanical behavior of bark of sunflower stem. Specimens were extracted at different locations in the stems and were conditioned in chambers of different relative humidity (RH) beforehand. In order to investigate the moisture variation within specimens during specimen's installation to testing machine, moisture diffusion coefficients of specimens were deduced assuming Fick's second law prior to mechanical tests. Results show that there was no significant moisture variation within specimens during specimen's installation. Tensile tests have been performed on specimens. Results show that greater Young's modulus was obtained for specimens extracted at higher location and conditioned at lower RH.

1 Introduction
The green industry is an important issue from both an economical and environmental point of view. In this context, researches dealing with the development of new bio-sourced materials attract an increasing attention. Recent developments have led to create a non-food agricultural sector for the use of by-products of agriculture in order to develop bio-sourced materials with high added value.

In Europe, sunflower is cultivated for the edible oil extracted from its grains. Sunflower is one of the three main sources of edible oil with rapeseed and olive. This plant is consequently widely cultivated and abundant. In this context, it is clear that the flower itself is the most interesting part of the plant. On the other hand, there is no significant industrial use of the stems. These stems however exhibit rather good mechanical properties (thanks to the bark) as well as good thermal property (thanks to the pith). Consequently, this by-product can potentially be applied for the manufacturing of bio-sourced materials, for instance for the thermal isolation of existing buildings [1].

The current study is a part of a more general project [1] dealing with the design of panels made of a bio-composite containing sunflower stems and a bio-matrix. Even if the thermal properties are the most interesting topics in this type of application, it is clear that these panels required minimum mechanical properties, at least for handling and fixing purposes. Hence the mechanical characterizations of the bark of stems are required. Tensile tests have been performed on specimens of bark. Attention was paid on the influence of the specimens' extraction location and specimens' conditioning relative humidity on mechanical properties: the specimens were in fact extracted at different locations in the stems and were also carefully conditioned at various values of relative humidity before the mechanical tests. Considering the fact that testing machines are not equipped with humidity conditioning chambers, the moisture content within the specimens would probably change during the period of the specimens' installation. In order to investigate this variation, moisture diffusion coefficients of specimens were deduced assuming Fick's second law [2] prior to mechanical tests.

In the following parts of paper the specimens' preparing processing, the testing method and the Young's modulus obtained on bark of sunflower stems are presented. The influence of conditioning RH on the mechanical properties as well as the influence of the extraction location of the tested specimen in the stem will also be discussed during the presentation.

2 Materials and testing methods

2.1 Specimens preparations

In order to find out if the Young's modulus of specimens of bark changes according its location in the sunflower stem, specimens extraction locations are defined as presented in Figure 1.

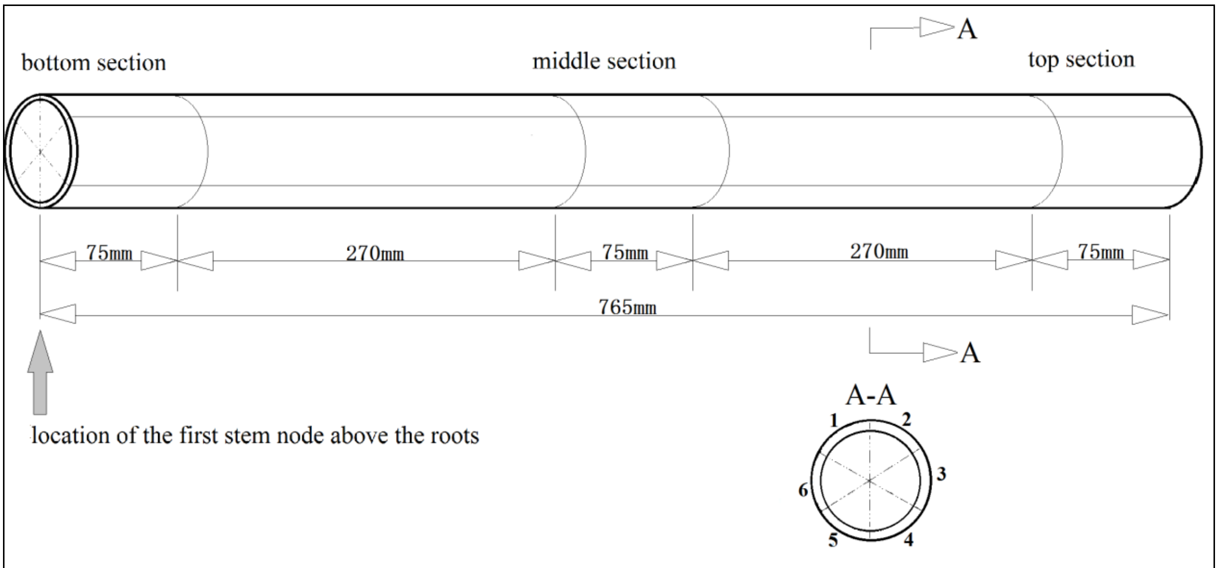

Figure 1. Definitions of specimen extraction locations in sunflower stems.

In each sunflower stem, three sections of 75mm (bottom, middle and top sections, see Figure 1) located at different height were chosen for manufacturing specimens. The bark surrounds the pith whose shape is similar to hollow cylinder as can be shown in Figure 1. The bark of sunflower stems of each section is divided into 6 specimens (see cross section A-A in Figure 1) in order to facilitate the implantation of mechanical tests. The inner surface of bark specimens were slightly polished with sand paper in order to obtain the nearly plane specimens (the outer surface of bark can't be polished because of the presence of some stiff fibers, see Figure 2).

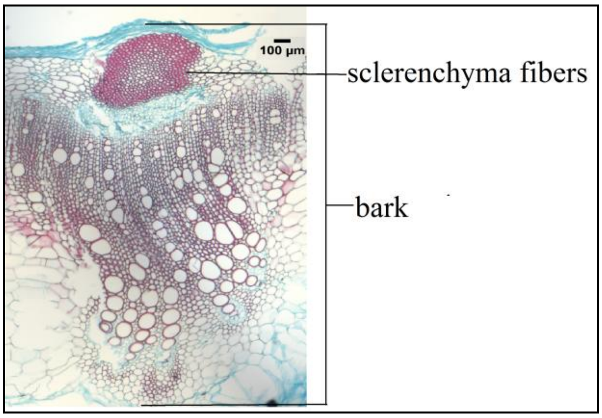

Figure 2. Cross section structure of bark of sunflower stem.

The specimens of bark were nearly rectangular shaped after polished. They have quite the same geometry for both of the hygroscopic and mechanical tests: the length of specimen varies from 55 to 60 mm; the width of specimen varies from 7 to 10 mm; the thickness of specimen varies from 1.2 to 3 mm. For hygroscopic tests, 36 bark specimens extracted from two sunflower stems were reused for the absorption / desorption test at 33% RH and 75% RH, thus 12 specimens were tested at each section and each RH. For mechanical tests, 90 bark specimens were cut in five sunflower stems, at each of the three locations two specimens were tested at the same RH (drying in an oven = 0% RH, 33% RH and 75% RH), thus 10 specimens were tested at each section and each RH.

2.2 Hygroscopic tests

Hygroscopic tests were performed in order to determine the moisture diffusion coefficient (D) of specimens of bark assuming to Fick's second law. This moisture diffusion coefficient is useful to estimate specimens' moisture content variations during specimen's installations in the testing machines (which is the period between taking specimens out of the conditioning chamber and stating the testing machine). The solutions of diffusion equations that characterize moisture transport in specimen of bark (plane sheet shaped) are described in [3]. D can be determined by substituting the specimens' moisture content variation *vs.* time into the corresponding solution of diffusion equation. The test consists in measuring the specimens' moisture content variation *vs.* time. Specimens were first dried in an oven with desiccant (P_2O_5) and then placed and kept in conditioning chambers with 33% RH or 75% RH until the saturation of water (absorption processes); the saturated specimens were then placed and kept in conditioning chambers with 8% RH which is the value nearest to 0% that can be obtained (desorption processes). These RH values in the conditioning chambers are obtained by the method described in [4]. Specimens' moisture content variation *vs.* time can be measured during these two processes then absorption and desorption moisture diffusion coefficients can be determined.

2.3 Mechanical tests

Mechanical tests were carried out at room temperature and RH. Specimens have been conditioned and equilibrated at different RH: 0% (oven dried with desiccant), 33% and 75% before tests.

Bark specimens were tested with DEBEN MCROTEST testing machine equipped with a load cell of 2 KN. The cross-head displacement rate was equal to 2 mm/min. Gauge length of specimens was adjusted to 30 mm. The longitudinal mechanical properties (Young's modulus, ultimate tensile strength) of bark specimens were then deduced by tensile test.

3 Results and discussion

3.1 Hygroscopic results

The moisture diffusion coefficient of specimens of bark was determined with experimental data and Fick's second law (see details in section 2.2). Figure 3 presents the moisture diffusion coefficients determined by absorption and desorption tests at 33% and 75% RH. Each bar in Figure 3 presents the mean value of 6 specimens (see section 2.1).

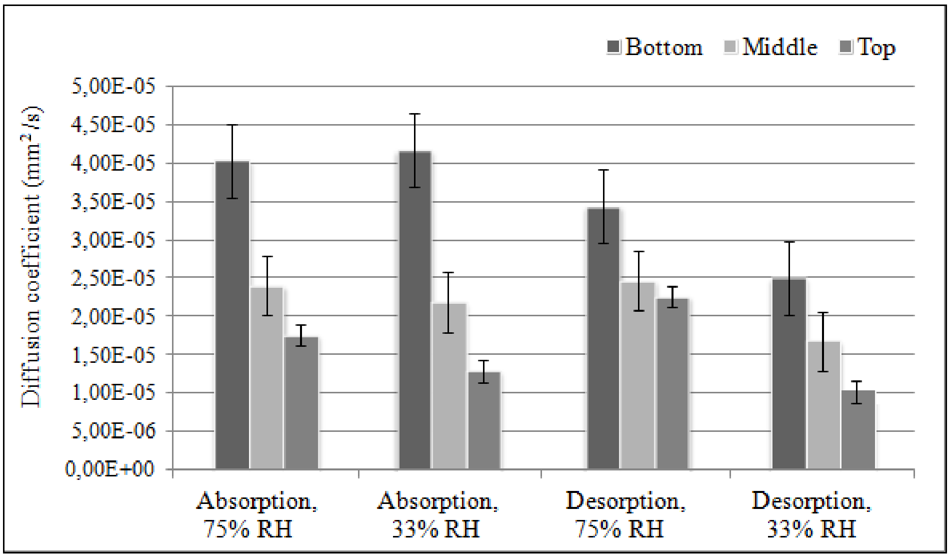

Figure 3. Moisture diffusion coefficients of bark specimens.

The same variation trend can be observed for the different tests represented in this figure. The D-value decreases with the extraction location along the sunflower stems. These D-values are averaged and used for estimating the moisture content variation described in section 2.2. By substituting the corresponding D-value in the diffusion equation [3], moisture variation within 60 seconds (time for specimen installation) is obtained (see Table 1). Results show that moisture content variations are not significant, and these variations will not influence the results of mechanical tests.

Specimen conditioning RH	Initial moisture content	Estimated finial moisture content
75%	12.94%	12.06%
33%	4.83%	4.6%
0%	0%	0.51%

Table 1. Estimation of final moisture content of bark specimen conditioned at different RH.

3. 2 Mechanical results

The Young's modulus of bark specimens was determined from the experimental data (stress – strain curve) of mechanical tests (see Figure 4). Each bar in this figure presents the mean value of 10 specimens (see section 2.1).

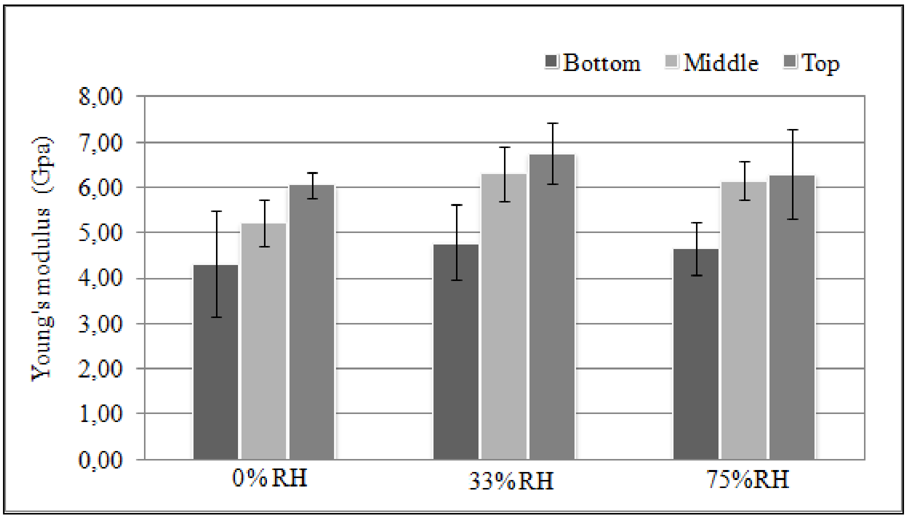

Figure 4. Young's modulus of bark specimens.

Similar Young's modulus *vs.* specimen extraction location variation trend can be observed for each RH from Figure 4. The Young's modulus of bark increases with the specimen extraction location along the sunflower stem which is contrary to the behavior of moisture diffusion coefficient. In addition, the moisture content of specimen has an influence on its Young's modulus: the Young's modulus decreases when increasing the conditioning RH from 33% to 75%. In other words, the Young's modulus decreases with the increase of moisture content in the specimens. However the results of dried specimens do not verify this trend. Their mean values are smaller than that of the specimens conditioned at 33% RH, but considering the slight differences between the mean values and the significant scatter, so the conclusion concerning the evolution of the Young's modulus is not so clear.

4. Conclusion

Sunflower stems were studied here in term of Young's modulus and moisture diffusion coefficient. The opposite variation trends of the Young's modulus and the moisture diffusion coefficient along the stems were observed. It was also found that the D-values are small and they vary between 1E-05 mm^2/s and 4.5E-05 mm^2/s. In consequence, these slight variations in moisture content of specimens do not influence the response of mechanical tests. The highest mean value of Young's modulus of bark is 6 GPa, which is found at 33% RH. This value is relatively satisfactory for bio-composite applications devoted to thermal isolation of existing buildings.

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