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3D structural characterisation, deformation measurements and assessment of low-density wood fibreboard under compression: The use of X-ray microtomography

E. Badel [a,*], C. Delisee [b], J. Lux [c]

[a] INRA, LERMAB, 14 rue Girardet, 54000 Nancy, France
[b] US2B, Domaine de l'Hermitage, 69 Route d'Arcachon, 33610 Cestas Gazinet, France
[c] LEPTAB, Avenue M. Crepeau 17042 La Rochelle, France

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Abstract

A low-density wood fibreboard has been compressed along its transversal direction. The experiment was carried out in ESRF synchrotron (ID19) and X-ray microtomographic images were recorded for each state. Stipulating that the fibreboard is a discontinuous material essentially made of air, that the compression simply re-organises the spatial distribution of the fibres and does not involve their intrinsic mechanical properties, we are able to deduce the material points density variations along the thickness of the panel. Good agreement is achieved between the macroscopic deformation of the sample and the microscopic compression rate evaluation. Then, the modifications of structural parameters are investigated by 3D image analysis. The relationship between the local structure and the behaviour of the wood fibreboard are deduced. Finally, a modelling approach allows the local densification to be predicted and confirms the initial hypotheses about the local behaviour of the material. In particular, polyester bonds are not involved.

Keywords: A. Fibre; B. Compression; C. Deformation; D. Non-destructive testing; D. X-ray tomography

1. Introduction

According to new normative laws, the designers pay more and more attention to the acoustic noise reduction and the thermal insulation of the buildings. For that purpose, the use of low-density material is clearly increasing. Because of their good thermal and acoustic performances and their very low cost, the insulation panels are still primarily made of glass wool (or rock wool). Their thermal, acoustic and mechanical properties have been widely studied to improve the manufacturing process [1,2]. The growing need for environmental friendly materials has stimulated an increasing interest in the natural fibreboards, and especially wood fibreboards. These are made of single fibres and bundles that are laid on a conveyor belt. Additional glue is usually used to ensure the cohesion when the panel enter in the hot press. Their technical properties however remain largely unknown. In the last few years, numerous studies have been initiated to characterize the behaviour and to understand the relationships between the nature, the size, the spatial organisation of the fibres and the properties in order to improve the manufacturing process. Most of these are dedicated to thermal properties [3–5]. Since these materials are not used as structural elements, there is little literature about the mechanical deformation of the low-density fibreboard [6] under mechanical stress, whereas the properties of singles fibres (rupture, elastic and visco-elastic properties) are widely studied for other wood based composite materials, paper or massive wood assessment purposes [7–11]. However, the deformation under stress behaviour is involved during the storage in the manufactures or at the retailers and during the

* Corresponding author. Tel.: +33 3 83 39 68 86; fax: +33 3 83 39 68 47.
E-mail addresses: badel@nancy.inra.fr (E. Badel), delisee@us2b.pierroton.inra.fr (C. Delisee), jerome.lux@univ-lr.fr (J. Lux).

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handling in the building sites. In this paper we investigate the compression of a low-density wood fibreboard perpendicularly to its main faces and the relationship between its behaviour and the local structure. This is observed in situ thanks to high-resolution X-ray microtomography that allows the organisation of the fibres to be followed in 3D during the compression test without external perturbation.

2. Material and method

2.1. Material

The material sample was taken from very low-density wood fibreboard used for thermal insulation of the building. It is composed of maritime pine fibres and bi-components thermo-fused polyester fibres to ensure cohesion. Wood fibres are composed of isolated fibres (average diameter and length around 40 μm and 1 mm) and bundles (aggregation of several fibres, with diameter and length up to 500 μm and 10 mm), showing strong variability of sizes. The diameter and length of polyester fibres are, respectively, 20 μm and 55 mm. A non-woven textile process, adapted to wood fibre based materials manufacture, produces a thick board with a 3D architecture. Before consolidation, the fibres are distributed and randomly oriented. Then the mat is rolled out at the required thickness and is consolidated in a kiln. This induces a main orientation along planes parallel to the faces [5]. The cohesion of this discontinuous matter is provided by fibre-to-fibre connections thanks to the fusion of plastic fibres (Fig. 1). The average macroscopic gravimetric density of the material is about 45 kg m^{-3}. A small cylinder was carefully extracted from the board for the mechanical test. The diameter and height were, respectively, around 10 mm and 12 mm.

2.2. Compression tests

The compression experiments were carried out in the X-ray microtomographic device installed at the ID 19 beam line of the European Synchrotron Radiation Facility (ESRF, France). A total of 2048^3 voxels volumes ($\approx 10.05^3$ mm) with a 4.91 μm spatial resolution were recorded. The grey level value of each voxel represents the average attenuation properties in this voxel.

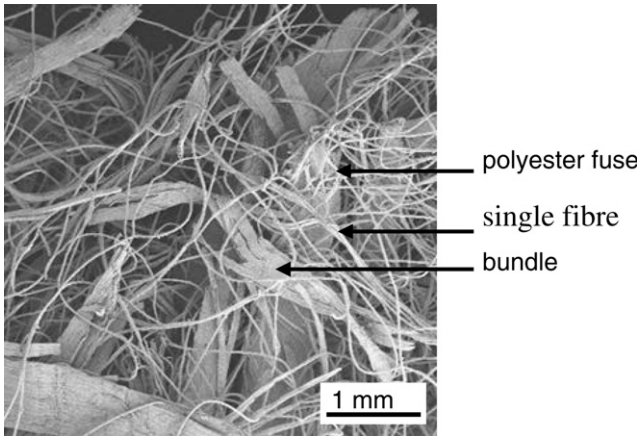

Fig. 1. SEM image of wood fibreboard. The wood bundles and fibres are connected by the thin polyester bonds.

Mechanical tests were conducted in a specially designed tensile/compression testing machine lent by the GEMPPM laboratory [12]. It is composed of two horizontal plates: one is fixed while the second is mobile and vertically translated with a motor. A PMMA tube transmits the vertical load (Fig. 2) perpendicularly to the surface of the panel. The sample is constrained in the tube (internal diameter equal to 10 mm) guaranteeing macroscopic 1D displacement. A pre-load was performed to ensure good contact between the sample and the plates. Then, two tomographic scans were recorded at two states of compression called "initial" and "compressed". The experimental macroscopic deformation was equal to −32.8%.

2.3. Crop of the 3D volumes

Sub-volumes were extracted from the raw data in the core of the sample, both to reduce the size of the file for its analysis and to avoid surface modifications induced by the material cutting. The final sizes of the sub-volumes were $1024^2 \times 1360$ pixels for the initial and $1024^2 \times 973$ pixels^3 for the compressed states. They are larger than the size of a REV (representative volume element) as previously estimated for this material by Lux [5].

2.4. Structural measurements

The visualisation and the basic image treatments were performed using ImageJ [13]. The structural measurements by 3D image analysis [14,15] were performed using Aphelion™. Morphological operations were used to characterize the two states of compression in different ways. First, the 3D images were thresholded in order to separate the solid phase and the air. Then, basic operations were applied to a set (of fibres or of pores). They are dilation and erosion by structuring elements that are reference sets of given geometry (segments, spheres, cubes, octahedrons, etc...). Usual composed operations are opening and closing which are, respectively, an erosion followed by a dilation and a dilation followed by an erosion.

2.4.1. Porosities

The total porosity, i.e., the volume fraction of air in the entire sample, was measured. It includes the air fraction outside the fibres and their internal porosity. The fibre porosity is related to the volume fraction of internal porosity (lumens included) in the wood particles. It is expressed in percentage of the volume of filled fibres. The fibres were filled (Fig. 3) using morphological operations [5]. Finally, it gives the porosity referred as external porosity, i.e., the volume fraction of air lying outside of the filled fibres.