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Accuracy of regular wood cell structure model

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ABSTRACT

The material rigidity of a cellular structure depends on numerous mechanical and geometrical parameters. This dependency was studied here by simulation on a micromechanical model. The rigidities of different cases were compared to the rigidity of the deterministic or exact case to find the effect of different parameters. The deterministic case was based on the mean values, whereas the geometrically exact model was based on the scanned image, and the different cases consider the variation in the thickness of the cell wall, geometry, and Young's modulus of the cell wall. The study concentrated on the cellular structure of earlywood in Norway spruce. The starting point was a set of earlywood structure images in an RT plane, from which geometry of the mid-cell wall and cell wall were extracted and used as the exact geometry. Geometric analysis in the statistical sense based on the cell wall lengths and thicknesses provided a statistical model for the cell's geometry.

1. Introduction

Wood is an abundant, moderately durable, and economically feasible engineering product. It is widely used in construction, furniture, paper and pulping, printing, and packaging industries. Despite its importance as a material used in engineering work, documentation of its material properties, such as rigidity and strength, is poor and the values contain large uncertainties compared to other engineering materials in common use, such as steel or aluminium.

The challenge in the mechanical modeling of wood is the large variation in rigidity and strength from specimen to specimen. The variations may largely be caused by the geometric structures on various scales and, in particular, by irregularities in them. The direct consequence of irregularity is the need for a statistical description of mechanical properties.

According to Mishnaevsky and Qing, 2008, most micromechanical models of wood are based on a honeycomb, where a hexagonal cell is repeated in a more or less regular manner (Gibson and Ashby, 1997; Zienkiewich and Taylor, 2002; Qing and Mishnaevsky, 2011). A few references consider the irregularity of wood by tracing the scanned image on a cell-by-cell basis (Persson, 2000; Holmberg et al., 1999; Kahle and Woodhouse, 1994; Rafsanjani et al., 2012). However, to our knowledge the regularity statistics for generating cellular material samples for finite element analysis have not been modeled thus far.

The aim of the present study is to quantify the effect of cell structure modeling on rigidity for the structure of earlywood in Norway spruce. It considers the effect of size and geometric as means of ascertaining the most important features to be included when considering rigidity. This is achieved by comparing the rigidity of a deterministic model based on the mean values or a geometrically exact model based on the scanned image to other models. These models are based on different statistical parameters of the cell's geometry. Two different sizes are studied for the deterministic case to see the effect of specimen size on the variation between specimens. Only one size of the geometrically exact model is used due to the limited size of the images.

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The starting point is a set of earlywood cell structure images in the RT plane. Descriptions of the extracted geometry of the mid cell wall and cell-wall thickness are used as the exact geometry. Geometric analysis in the statistical sense and geometry based on the statistics of the cell wall's length, direction, and thickness provide a simplified statistical model of the cell's geometry. The deterministic model, based on a regular cell structure, takes only the mean values into account.

The effect of geometric features and the specimen size (in terms of the number of cells) of a specimen on rigidity is studied by simulating a micromechanical model. The cell's structure is modeled as an elastic planar beam truss subjected to external stress. The corresponding strain, and thereby the measure of rigidity, is obtained as a part of the solution.

2. Earlywood cell geometry

Cell structure of earlywood was studied using 10 images in the RT plane (illustrated in Fig. 1). The wood samples were cut from the same 60-year-old Norway spruce stem grown in Finland. All samples were from mature wood, with the growth ring number being approximately 45–50; only earlywood was considered. Rays were neglected in the analysis. An estimation of the effect of the rays on the mechanical properties can be found in a study by Bergander and Salmén (2000).

2.1. Geometry extraction

In order to form a sample of softwood for modeling purposes, several options have been proposed in studies by Astley et al. (1998) and Persson (2000). In this study, the starting point for the process is the binarization of the actual Norway spruce images. As in conventional pattern recognition studies (Chung et al., 2010; Bovik, 2005), the separate cell regions are defined and their cell centroids calculated. Cell vertices, shown as white points in Fig. 2, are detected using the intersections of the adjacent cells, which are sorted based on the nearest neighbor classification scheme (Narendra and Fukunaga, 1977; Khedr and Salim, 2008).

The cell wall thickness, t, is obtained as the distance between a vertex point and its nearest neighboring point inside the related cell region (shown in white in Fig. 2). The distance is used to define the radius, r, of a circle, in which the centre point is located at the vertex, as shown in Fig. 2. Cell wall thickness, t, is defined as the mean value of the circle's diameters for two neighboring vertex points.

A description of the cell's geometry in terms of the vertex points and cell wall thicknesses, which were extracted as explained above, serves as the exact data. The size of the

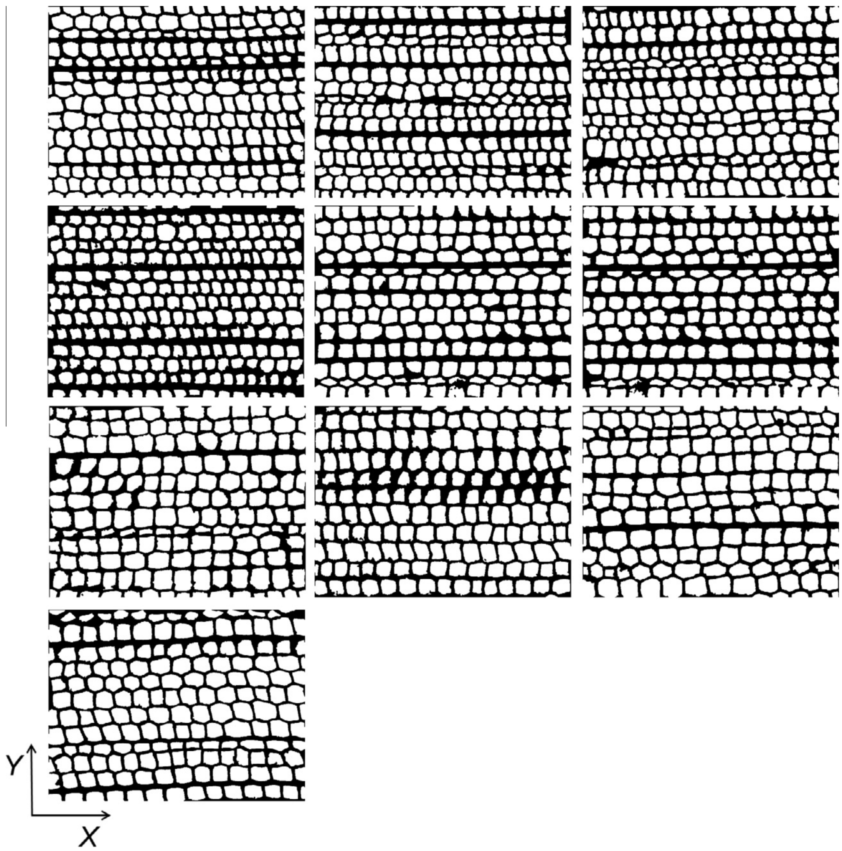

Fig. 1. Earlywood images numbered from 1 to 10, left to right, top to bottom.