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Modeling of damage evolution in soft-wood perpendicular to grain by means of a discrete element approach

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Abstract

The anisotropy of wood within the radial–tangential (RT) growth plane has a major influence on the cracking behavior perpendicular to grain. Within the scope of this work, a two-dimensional discrete element model is developed, consisting of beam elements for the representation of the microstructure of wood. Molecular dynamics simulation is used to follow the time evolution of the model system during the damage evolution in the RT plane under various loading conditions. It is shown that the results are in good agreement with experiments on spruce wood, and that the presented discrete element approach is applicable for detailed studies of the dependence of the microstructure on mesoscopic damage mechanism and dynamics of crack propagation in microstructured and cellular materials like wood.
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1. Introduction

Wood is probably the most ancient structural material in the world, widely used today in many species, for all kinds of purposes, leading to a world production of roughly 10^9 t, which is about even to the one of iron and steel [1]. Its application in modern civil constructions of large dimensions like stadium roofs or long-span bridges calls for a good understanding of design properties like moduli, crushing strength and toughness. Wood is a natural fiber composite, which is strongly orthotropic due to its internal material structure. The elemental material is a cellulose cell wall material with equal properties for different species [1]. Nevertheless, macroscopic properties vary highly within the tree, among different species and along loading directions. Explanations for these extreme differences are found on the microstructural level in the cellular structure. Several internal length

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scales can be found, that are relevant for the damage evolution, including many defects. Depending on the observation scale and position, wood shows different physical and geometrical properties. The size scales are typically subdivided into hierarchical levels like the atomic, micro, meso and macroscale. The material can be regarded as a cellular structure with hexagonal shaped wood fibers arranged in parallel on the microscale (comp. Fig. 1). The dominating structure on mesoscale in the RT plane, perpendicular to the tree axis, are annual rings with an alternating early- and latewood that differ in fiber shape and thickness of the cell walls. For the understanding of damage in wood, damage mechanisms on the micro and mesoscale are of special interest.

Discrete element methods (DEM) are a fast emerging computational method designed to solve problems with gross discontinuous materials and geometrical behavior. Due to the creation and continuous motion of evolving crack surfaces, fracture of material is difficult to handle numerically. Continuum models have problems to account for the discrete nature of material failure. One approach is a smeared crack approach, e.g. with a microplane damage model [2], where the

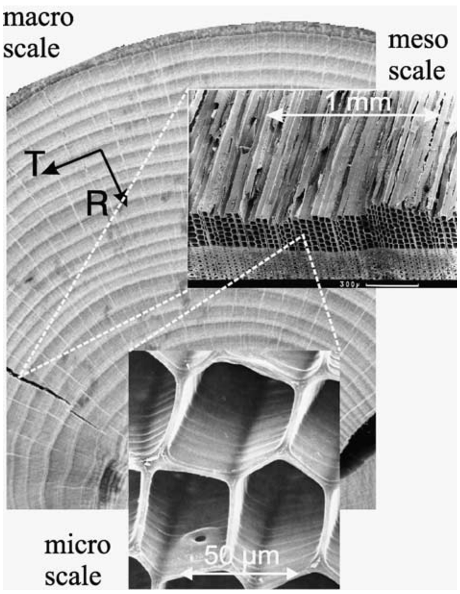

Fig. 1. Relevant scales in wood (microscale picture from [8]).

influence of the damage is considered in terms of the material properties. The other approach is to continuously change the model topology, as cracks evolve [3]. Alternatively, discrete models like lattice dynamics models can be used to simulate fracture [4]. A common type of question around DEM is related to the possibility of assigning continuum properties to a given lattice structure, especially avoiding artifacts e.g. due to a regular microstructure of a model. Contrary, for the representation of wood, a regular microstructure like a hexagonal lattice is especially suited for naturally taking the anisotropy of wood in the RT plane into account.

In the present paper fracture of wood was studied with a combined beam-particle lattice model on the micro- and mesoscopic scale. The mesoscopic structure of annual rings is projected on the microscopic model and generic failure mechanisms, observed in the failure of spruce wood in the RT plane, are implemented into the model. The paper is organized as follows: Section 2 gives a detailed description on experimental in situ studies of the fracture processes in clear soft-wood under various loading conditions perpendicular to grain. Experiments are focused on the micro–meso-structural scale, using a confocal laser scanning microscope (CLSM). Identified generic damage mechanisms are the rupture of earlywood cell walls for crack propagation in tangential direction and debonding of the interface of wood fibers for crack propagation in radial direction. Section 3 provides an outline of the theoretical background of the discrete element model, for the microstructure of wood. After the model description, test simulations and damage simulations are presented and compared to the experimental findings in Section 4.

2. Damage in wood in the RT plane

Damage basically initiates on the atomic scale and reaches relevance for larger scales like the micro or mesoscale while it propagates, leading to global failure when reaching the macroscale. For the prediction of the damage evolution in materials scale dependent knowledge on their relevance for the damage evolution is indispensable

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