IN-SITU SYNCHROTRON BASED TOMOGRAPHIC MICROSCOPY OF UNIAXIALLY LOADED WOOD: ***IN-SITU TESTING DEVICE, PROCEDURES AND EXPERIMENTAL INVESTIGATIONS***

Dissertation, ETH Zurich, 2014, ETH-No. 21620, **Michaela Zauner**

Wood has been an important material for building in the past and is gaining increasing interest in the present. To better use the material, detailed knowledge of the behavior under mechanical and hygroscopic load is necessary. For this, amongst others, models are continuously developed.

Therefore physical properties have been the focus of extensive scientific research. Particularly, the determination of elastic properties and macroscopic strength are of primary interest. But due to its complex and variable microstructure, the behavior of wood is not completely predictable with macroscopic models. Therefore knowledge at different hierarchical levels is beneficial, as the evolution of mechanical processes and failure mechanisms depends on the structure and the stress on the sample. The microscopic mechanisms leading to ultimate failure of the material have been observed after failure without monitoring of the damage progression, and for selected thin samples of the total volume. Additionally, failure of cell elements isolated from tissue has been investigated. The deformation of cells inside the non- and pre-damaged composite has not been the focus of extensive research.

Non-destructive methods are necessary to monitor the three-dimensional behavior of the wood cell structure under load. In particular, synchrotron radiation-based computed tomography (SRbCT) allows monitoring of arbitrary three-dimensional material structures with microscopic resolution and faster data acquisition than for a common x-ray computed tomography (depending on the quality starting from half a second).

In this thesis, a portable mechanical loading device was developed for on-site operation at the Synchrotron radiation microscopy laboratory at the TOMCAT beamline (Swiss Light Source (SLS) at the Paul-Scherrer-Institute). The installation was applied to experimentally monitor the three-dimensional microstructure of wood at specific loading states.

A main objective was the construction of a mechanical testing device with fast adaptability for tension and compression tests, and the design of sample geometries, production and testing methods. A suitable specimen shape, for which the highest percentage of failure occurred in a defined small field of view at the center of the specimen, was determined and verified. Next, comparative studies between surface deformations and strains determined with Digital Image Correlation observed in the small field of view were performed and the strains gained through the deformation over the complete sample length evaluated. The correlation of density with compressive strength was proven for the sample geometry and a possible size effect was found for up-scaled speci-mens.

Two softwood species (*Picea abies* [L.] Karst and *Abies alba* Mill.) and one hardwood species (*Fagus sylvatica* L.) were tested under increasing compressive load in the longitudinal direction with two different spatial resolutions to evaluate and determine plastic deformations. First, the original structure was recorded and afterwards modifications visible in tomograms acquired at equidistant steps were investigated with respect to the initial tomograms. With this method, the origination and development of plastic failure processes were assessed and described for different structures.

For the first time, the initiation and further progression of deformation during compressive load was shown for isolated structures (like vessels and tracheids) from inside a complete wood sample to illustrate the deformation mechanisms and origination under compression. Mainly telescopic shortening and buckling, previously found in literature, as well as a combination of both, were identified. Single cell-width wood rays and resin channel seemed to deform equally with the surrounding tissue without contributing to the strength or a deflection of the failure lines. Further, the failure areas in the form of kink lines could be isolated and described for latewood of soft-wood, hardwood and specific material compositions. The failure area was automatically deter-mined by monitoring the change of the density in the sample.

Finally, to evaluate the set-up for tension, one wood species was loaded in two different directions (longitudinal and radial), combining acoustic emission and synchrotron radiation-based computed tomography in-situ. The experiments were conducted successfully and significant differences in the acoustic signal strength, distribution and onset between the two loading directions could be shown. In the acquired tomograms, the failure region for radial loading and the starting fissure for axial loading were successfully isolated. Similar to compression, distinct failure mechanisms were found for each direction and the influence of wood rays and resin channels was de-scribed. For radial loading, fiber bridging and varying cell wall failure mechanisms could be shown.

Overall, this thesis introduced a complete set-up for tensile and compressive in-situ tests in combination with synchrotron micro-tomography, available for future use and purposes. Observations of initiation and development of failure in tension and compression were successfully executed for different wood species and compositions. A combination of procedures with additional measurement methods was realized and future applications for different structures, higher resolutions and loading modes were suggested. For the first time, the development of failure mechanisms of single elements inside an undamaged structure could be observed for tension and compression. The data generated by the proposed combination of methods, can be used to quantify failure processes and deformations occurring during an increase of load.