Microfracture in wood monitored by confocal laser scanning microscopy

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Abstract The paper deals with the experimental characterisation of damage evolution within the radial (R)–tangential (T) growth plane of softwood loaded in tension perpendicular to the grain. The reported investigations comprise in-situ monitoring of crack propagation by means of Confocal Laser Scanning Microscopy (CLSM) and evaluations of crack patterns of broken specimens. Three types of notched specimens, representing different crack propagation systems, were tested; for all configurations, both, loading and crack propagation direction were located within the RT plane of wood. The CLSM pictures of broken specimens show distinct differences among the regarded configurations with respect to crack paths. Two different damage mechanisms were identified being rupture of earlywood cell walls in the case of crack propagation in tangential direction and debonding of wood fibers, i.e. rupture of the interface zone between adjacent tracheids, in case of crack progression in radial direction. In the case of an intermediate crack system with an angle of 45° between initial notch direction...
and radial direction the crack evolution was monitored in-situ during the tension test, whereby the combined action of both basic fracture mechanisms was observed.

**Introduction**

The natural fiber composite wood exhibits strongly anisotropic properties with respect to stiffness and strength. Tension stresses from external loads or induced by transient ambient conditions – such as moisture and temperature gradients – are most unfavourable for the directions perpendicular to grain, i.e. perpendicular to direction of the wood fibers. Crack initiation and propagation within the weakest plane of the material wood caused by tension stresses perpendicular to grain is therefore a major issue of research activities in the field of wood (fracture) mechanics.

Considerable efforts have been undertaken to obtain fracture mechanics parameters of RL and TL fracture configurations or crack systems, where crack propagation is parallel to the longitudinal (L), i.e. fiber direction, while load direction resp. normal vector of crack surface is parallel to radial (R) or tangential (T) growth direction. (e.g. Valentin et al. 1991; Bostrom 1992). The present investigation, however, focuses on the characterisation of RT, TR and intermediate crack systems, whereby both, the load and the crack propagation directions are located within the end-grain face.

The latter crack systems are of special practical relevance in the case of tension stresses perp. to grain in curved or tapered glulam beams. Earlier studies (Aicher et al. 1998, Dill-Langer et al. 1999) have shown, by means of numerical calculations and by empirical evidence that Mode I cracks in glulam due to tension perpendicular to grain are most often initiated near mid-width of the lamellas. This fact results from the pronounced stress peaks due to polar anisotropy within the RT-plane (Aicher and Dill-Langer 1996). The initial cracks most often propagate globally parallel to the wider sides of the lamellas towards the outer edges of the boards whereby the crack system is varying from RT (initial) to intermediate systems and in extreme cases finally to TR orientation. Complex macroscopic crack patterns were observed in the intermediate range where the annual ring structure obviously interacts with the propagating crack yielding in some cases crack-stop behaviour accompanied by global load recovery. Therefore the knowledge of crack-propagation properties as related to the meso-structure at annual ring level as well as to the micro-structure at tracheid level is an important prerequisite to assess the global damage behaviour of structural sized solid wood or glulam members loaded by transverse tension stresses.

The inspection of fracture surfaces by means of microscopic imaging is a common method in wood science in order to characterise damage features and mechanisms. Most frequently fracture surfaces of failed specimens have been investigated by Scanning Electron Microscopy (SEM). Most literature known studies deal with tension parallel respectively perpendicular to grain; in the latter case predominantly RL and TL crack systems are regarded (e.g. Debaise et al. 1966; Borgin 1971; Coté and Hanna 1983; Zink et al. 1994; Zimmermann et al. 1994). However, the analysis of fracture surfaces provides only limited insight in the damage mechanisms. Therefore in some investigations specimens were not loaded completely until failure but to a certain stage of damage; then the inspection of the surface was performed (e.g. Job and Navi 1996). The monitoring of crack growth in-situ during application of the load, yielding the most complete representation of the damage mechanisms, is reported very scarcely in literature.