Orthotropic Single-Surface Plasticity Model for Spruce Wood including the Effect of Knots

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Abstract

In this contribution a brief overview of the development of an orthotropic material model for the simulation of spruce wood under simultaneous plane and transverse shear stresses is given. The model considers an initially linear elastic domain as well as plasticity behaviour including hardening and softening mechanisms at higher states of stress and strain, respectively. The newest feature of the material model is its ability to consider the effect of knots on the strength properties of the different principal material directions of spruce wood.

1. INTRODUCTION

For the development of a constitutive material model for spruce wood different types of experiments are required. During the 1990's a test series on clear spruce wood subjected to biaxial states of stress has been performed. These tests were designed for the investigation of stress states with their principal directions being oblique to the longitudinal and radial direction of wood. In 2003 and 2004 additional tests were performed filling up the lack of experimental information with respect to the tangential direction and knots.

The mechanical behaviour of the principal material directions as well as the influence of knots on the strength properties are necessary for realistic finite element ultimate load analyses of multiaxial loaded structural details as well as of shell structures made of wood. Uniaxial experiments in different material directions with knots were performed, too. Results of these tests and consideration in an orthotropic material model will be presented and discussed in this contribution.

2. CONSTITUTIVE MATERIAL MODEL FOR CLEAR SPRUCE WOOD

The properties and the concept of the single-surface plasticity model are summarised in MÜLLNER et al. [1]. This material model can be used for the simulation of clear spruce wood under simultaneous biaxial in-plane stresses. The extension of the material model for transverse shear stresses was done by MÜLLNER et al. [2]. The formulation of a non-associated hardening and softening rule allows the consideration of several modes of failure identified with the results of the experimental investigation. In Fig. 1 the used yield surface is shown.

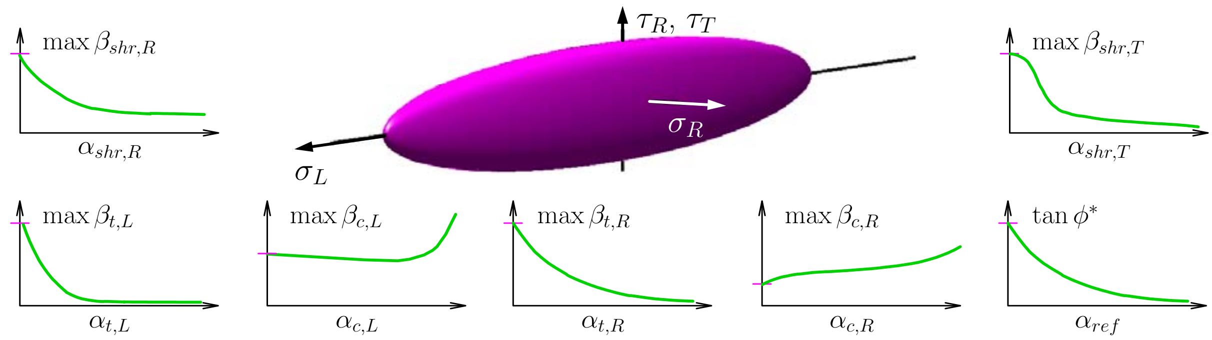


Figure 1 - Yield surface of single-surface material model in the orthotropic stress space and evolution laws for the strength values depending on the strain-like primary variables α_i

The formulation of the seven evolution laws, shown in Fig. 1, requires seven control variables. These so-called primary variables are collected in a vector α. The determination of α is subject to the non-associated hardening and softening rule. This rule considers the different modes of failure which were identified as:

- brittle tensile failure in fibre direction,
- compressive failure with densification in fibre direction,
- brittle tensile failure perpendicular to grain, and
- ductile compressive behaviour with densification perpendicular to grain.

3. CONSIDERATION OF THE EFFECT OF KNOTS

According to the different experiments, the extension of the material model for the consideration of knots was done in two steps. First, the mechanical behaviour of spruce wood in the tangential direction was investigated. The cross sections of boards and beams, which are widely used in timber engineering, are characterised by fibre orientations in *R*- as well as in *T*-direction. Compared to the *L*-direction, the material behaviour in *R*- and *T*-direction is similar (see Fig. 2). Therefore, it is possible to reduce the mechanical behaviour in *R*- and *T*-direction to a $\overline{RT}$ -equivalent. This fact leads to use the same transversely isotropic material model as for the *LR*-plane in the elastic region for spruce wood.

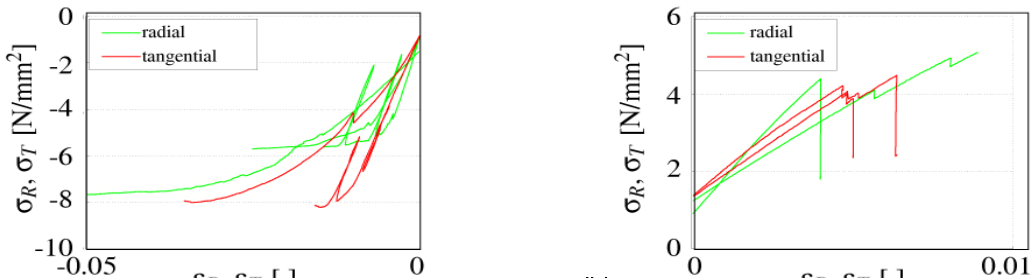
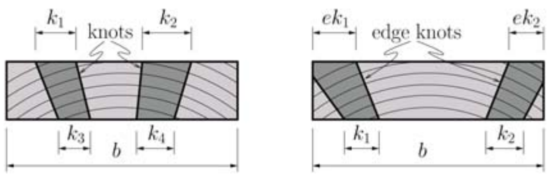


Figure 2 - Characteristic stress-strain curves for (a) compressive and (b) tensile loading

Second, because knots are a commanding criterion of wood, the material model was extended by the influence of knots on the strength values which are used in the material model. This fact is inseparably combined with the deviation of the fibre direction around the knots. Therefore a knot factor *ksa* has been defined, as shown in Fig. 3.



$$ksa = \frac{\sum_{i=1}^{m} k_i + s \cdot \sum_{j=1}^{n} ek_j}{2\,b}$$

k_i ... width of a knot
ek_j ... width of an edge knot
s ... increase factor for edge knots
b ... width of a board

Figure 3 - Knot factor *ksa* for the consideration of knots in the material model

The influences on the failure strength for tension loading and on the yield stress for compression loading, respectively, will reduce the size of the elliptical yield surface. In Fig. 4 an example for a knot factor of *ksa* = 0.20 for the tension strength in fibre direction is given.

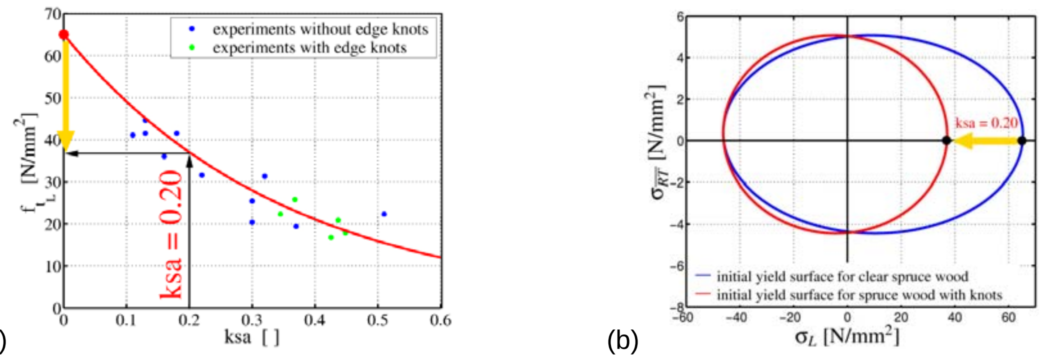


Figure 4 - Modelled Wood with knot (a) changing of tension strength (b) changing of yield surface

4. REFERENCES

[1] H.W. Müllner, P. Mackenzie-Helnwein, J. Eberhardsteiner: Constitutive Modelling of Clear Spruce Wood under Biaxial Loading by Means of an Orthotropic Single-Surface Model under Consideration of Hardening and Softening Mechanisms. Proceedings of the 2nd International Symposium on Wood Machining (2004): 83 - 90.

[2] H.W. Müllner, P. Mackenzie-Helnwein, J. Eberhardsteiner: Constitutive Modelling of Biaxially Stressed Wood for the Analysis of Layered Wooden Shells. Proceedings of the 3rd International Conference of the European Society for Wood Mechanics (2004): 277 - 284.