A combined material model for plasticity and fracture for wood

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1 Introduction

Wood and other composite materials are highly anisotropic due to their internal composition. Thus, anisotropic stiffness and strength as well as different failure modes have to be considered. In the following, a material model for wood for use in numerical simulations is presented. It takes into account orthotropic material behavior with respect to stiffness as well as strength and distinguishes between brittle and plastic failure modes: brittle failure modes occur in tension and shear, while plasticity is dominant in compression.

2 Theory & Implementation

The material model is implemented into the finite element software Abaqus by means of a user-defined material for stiffness and plasticity (UMAT) as well as using the XFEM-method for crack initiation and propagation in combination with a user-defined damage-initiation criterion for brittle failure (UDMGINI).

2.1 Elasticity

Orthotropy in the elastic domain is comparably simply implemented by an orthotropic stiffness matrix. The stiffness components (as well as the parameters governing plasticity and brittle failure) are defined via the input file; no hard-coding of the FORTRAN code is needed.

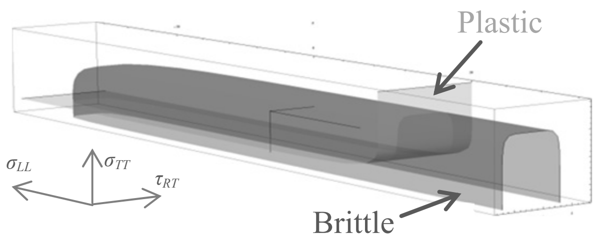

Figure 1 Combination of failure surfaces for plastic and brittle failure modes by super-ellipses

2.2 Plasticity

In the compression domain, failure is governed by plastic behavior. The basic implementation is a multi-surface plasticity model [2], allowing for multiple or only a single failure surface to be active at a time. As a novelty, a super-elliptic surface is implemented [1] but also other basic surfaces (planes, Tsai-Wu, von Mises) can be used and combined if needed. Perfect plastic behavior and associated plasticity are assumed.

2.3 Brittle failure

Brittle failure is initiated in case a failure criterion is reached whereby only tension and shear stresses are considered. Two main different approaches are implemented: in the first, multiple surfaces are defined for tension and shear directions, together with certain interaction criteria. Each of the surfaces is furthermore defining a separate failure mode and crack plain. The second criterion is again a single surface, based on a super-ellipse; different failure modes and crack planes are distinguished in addition. Traction-separation laws are defined for each failure mode. Those govern the softening behavior once cracks are active at the material point.
Figure 1 shows the combination of plastic and brittle failure surfaces when using super-elliptic surfaces. The strong curvature in the edge and corner regions can be seen while at the same time regions of low curvature occur in the normal directions. The advantage of this approach is the ability to create more flexible failure surfaces while at the same time avoiding the numerical difficulties encountered when using multi-surface plasticity models.

3 Examples

As seen in Figure 2, the simulation allows for a realistic estimation of the stiffness and failure modes of a woodworking joint. The regions under high compressive stresses perpendicular to the grain plastify whereas crack occurs where maximum shear stresses are encountered. Failure due to cracking and plastification can be identified separately, though both failure modes can happen in the same element simultaneously.
The model has also been deployed for the simulation of different structural details, amongst others joints (dowel-type connections, traditional wood-working joints) as well as structural details (beams with holes, notched beams). It is hence possible to run extensive parametric studies with respect to material properties and geometry and derive coherent conclusions.

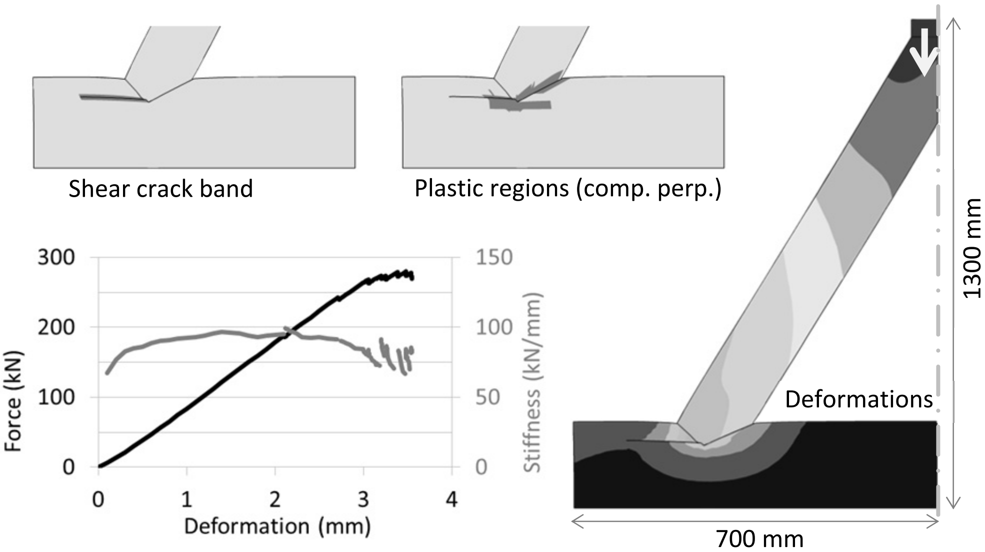

Figure 2 Geometry and results for a woodworking joint

References

[1] Dorn, M. (2014) *Proposal for a Failure Surface for Orthotropic Composite Materials*. Proceedings of the 11th World Congress on Computational Mechanics (WCCM XI).
[2] Simo, J. C. and Hughes, T. J. R. *Computational inelasticity*. Springer, 1998.