Engineering Fracture Mechanics 176 (2017) 83–99

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

journal homepage: www.elsevier.com/locate/engfracmech

A microstructure-based multisurface failure criterion for the description of brittle and ductile failure mechanisms of clear-wood

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ARTICLE INFO

Article history:
Received 16 December 2016
Received in revised form 21 February 2017
Accepted 21 February 2017
Available online 24 February 2017

Keywords:
Wood
Failure mechanisms
Unit cell method
XFEM

ABSTRACT

The failure behavior of wood, a complex natural composite, highly depends on structural features on several lower length scales. Thus, a new approach for the prediction of failure mechanisms of wood is proposed, aiming at a better description of mechanical processes in wood by taking the influence of microstructural characteristics into account.

Previously proposed failure criteria for wooden cells are now linked to unit cells at the annual ring scale. Extensive investigation of load combinations allow the identification and classification of the main failure mechanisms of clear-wood. Based on these findings, a multisurface failure criterion is formulated, indicating brittle as well as ductile failure mechanisms and giving interesting insight into the failure behavior. A new algorithm is presented, which enables the simultaneous description of plastic failure and cracking within numerical simulations. Finally, the failure criterion is validated for biaxial experiments and applied to a timber engineering example.

1. Introduction

The future competitiveness of wood compared to other building materials, like masonry, steel or concrete, highly depends on the development of sophisticated simulation tools. Here, one of the main challenges encountered is the prediction of load bearing capacities based on realistic failure mechanisms. The development of new or optimization of existing wood-based products and the combined use of wood with steel, for example in dowel-type timber connections, requires the description of mechanical processes in wood even after the point of failure. Formation of cracks or ductile mechanisms could be allowed for particular loading situations to better exploit the potential of wood.

Due to the complex microstructure of wood, traditional strength prediction methods are usually not able to capture the mechanisms, close to or after the point of failure, correctly. Frequently used failure criteria for orthotropic materials, which are based on the evaluation of maximum stress or strain values, vastly underestimate the load-carrying capacity of timber elements, as very local peak values not necessarily lead to structural failure, because of stress redistribution effects, such as localized cell wall failure. This fact can be taken into account by the use of so-called mean stress approaches [18,28], where stress values are averaged over finite small areas and then used to estimate the point of structural failure. Various researchers combined this method with findings of linear elastic fracture mechanics and applied it to wood [35,37,38,31]. A closer inspection of actual starting points of failure in experiments showed that, at least on a single board level, the effects of inho-

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http://dx.doi.org/10.1016/j.engfracmech.2017.02.020
0013-7944/

mogeneities, like knots, cannot be neglected. Thus, the implementation of fiber deviation models [11,12] is the first step toward the consideration of wood specific failure mechanisms. Such an approach led to a new structural failure criterion based on the evaluation of stress states in the vicinity of knots, proposed by two of the authors [23]. Furthermore, the capability of the numerical simulation tool to depict stress- and strain fields in wooden boards with sufficient accuracy was shown in Lukacevic et al. [25]. Like in [33], this simulation tool utilized a classic, orthotropic failure criterion in combination with elastic-plastic material behavior. To overcome limitations of such models, e.g. their inability to capture differences in compressive and tensile behavior very well, several researchers developed multisurface plasticity models for clear wood [27,1] or even combined those with cohesive zone models for the description of brittle failure mechanisms under tensile and shear loading conditions [34]. Dourado et al. [5] combined experimental data and a genetic algorithm in their determination of crack properties in cohesive crack simulations. Cohesive zone models were also used in the investigation of glued laminated timber beams with holes in [3]. Such an approach is limited to applications, where the crack path is obvious beforehand and, thus, can be predefined. A first approach to tackle this problem was presented in [15], where an iterative procedure with a step-by-step insertion of such cohesive elements was used instead of a predefined crack path. The importance of considering structural features for the correct modeling of fracture mechanisms has also been shown in the development of morphological lattice models [7,19,20] and other hierarchical computational models [30,32], where for two-dimensional simulations the explicit representation of early- and latewood was necessary.

In Lukacevic et al. [26] we proposed a new approach, where failure mechanisms are based on detailed material models on lower length scales (see Fig. 1). With such a procedure the amount of fitting parameters and the need for extensive identification experiments should be reduced to a minimum. In the first step of our modeling strategy, failure mechanisms of the two main clear wood layers, late- (LW) and earlywood (EW), were identified at the wood cell level by using an approach based on the XFEM. Only few assumptions on failure mechanisms of cell wall and surrounding material were necessary. The results from an extensive range of loading combinations were then used to derive two multisurface failure criteria for the two cell types, which were already used for simulations and validation at the annual ring level [26,24].

In the present paper, in a next homogenization step, the two new multisurface failure criteria will be applied to a new unit cell at the annual year ring level, where LW and EW will be modeled individually but as homogeneous layers. To allow the simultaneous use of plastic failure and crack initiation surfaces within a commercial FE software, an appropriate algorithm for such multisurface failure criteria has been developed and implemented. Another extensive parameter study on loading conditions then leads to the identification and classification of the main failure mechanisms at the clear-wood level. The results on this length scale are used to obtain a single multisurface failure criterion for clear-wood, where the so-called XFEM-based cohesive segments method is used to describe brittle failure mechanisms under tensile and shear loading, and

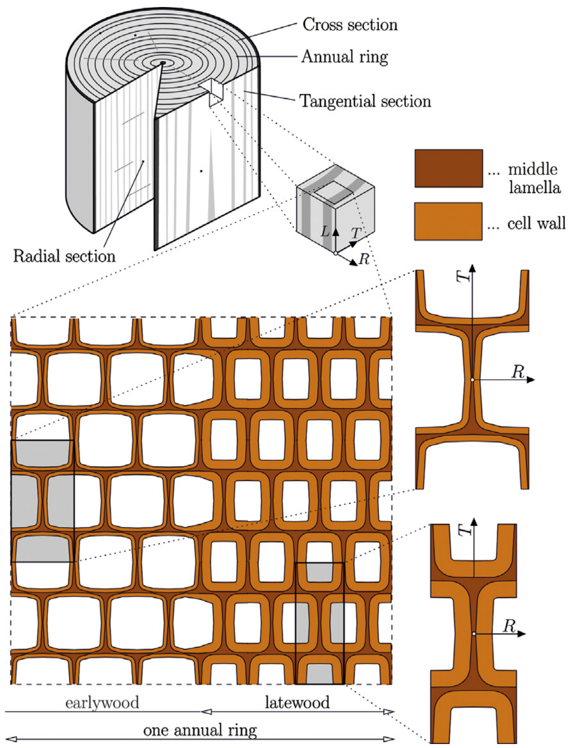

Fig. 1. Modeling approach for the determination of a multisurface failure criteria based on structural features on lower length scales [24].