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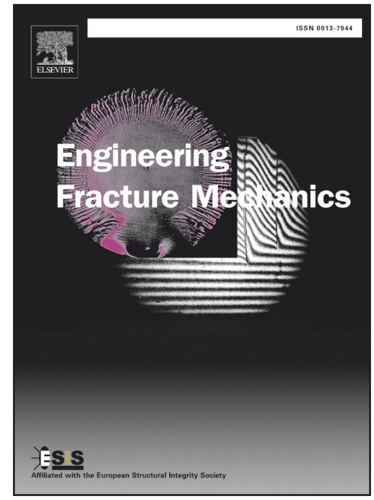

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Failure mechanisms of clear wood identified at wood cell level by an approach based on the extended finite element method

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Abstract

Within wooden boards, initiation and global direction of cracks are governed by structural features on the microscale. Thus, and to account for the layered structure of wood, all possible failure mechanisms for two repetitive units are identified by an approach based on XFEM. The resulting failure modes of 800 numerical fracture simulations for each cell type are classified and lead to the definition of two multisurface failure criteria. Finally, these criteria are applied to tensile tests at the annual year ring scale, showing that the developed approach is able to reproduce essential failure mechanisms in wood correctly.

Keywords:
wood, failure mechanisms, unit cell method, XFEM

1. Introduction

Wood is one of the oldest but still highly used building materials. Its excellent mechanical and physical properties combined with the general trend of growing environmental awareness in civil engineering have led to an increasing demand for wooden building structures in recent years. This trend is strongly inhibited by the less sophisticated prediction of the mechanical behavior of wood as opposed to other building materials.

Here, one of the major tasks is the reliable estimation of the bearing strength of wooden structures, which allows a more efficient use and a better utilization of wood and wood composites. For this, several methods exist, which take the complexity of this naturally grown material more or less into account. A brief overview of the existing methods is given in the following.

In general, failure in wood is induced by growth irregularities, which cause very localized stress peaks. Plastic effects, such as cell wall failure, reduce these stress peaks and allow for stress redistribution. For this reason, the stress state/field at which structural failure occurs is very difficult to estimate. The use of traditional maximum stress failure criteria with an evaluation of the stress state at the integration point level leads to an underestimation of the load carrying capacity. One possibility to overcome this problem is the use of so-called *mean stress approaches* [22, 19], where averaged stresses over a finite small area are assumed to indicate failure. These areas can be adjusted to typical features of wood, such as structural characteristics of wood fibers [1]. Serrano and Gustafsson [33], Sjödin and Serrano [34] and Sjödin et al [35] applied this approach in combination with findings of linear elastic fracture mechanics. They investigated single and multiple dowel connections, where the size of the finite area was governed by the fracture properties of the material. The suitability of different volume definitions, over which the stresses are averaged, and also the efficiency of various failure criteria was compared by Guindos [13]. Lukacevic and Füssl [20] presented a physically-based structural failure criterion, where it was assumed that in wooden boards with knots, global failure can be related to a stress transfer mechanism, which is identifiable by evaluating averaged stress fields in the vicinity of knots.

Either way, such models are mostly dependent on empirical parameters and the true failure mechanisms cannot be mapped. This can be overcome by directly modeling fracture processes. Common damage models, which are applied successfully for other building materials like reinforced concrete, are usually not suitable for wood due to its highly brittle failure mechanisms. Therefore, several researchers used so-called cohesive elements to model cracks directly. Schmidt and

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