Applying the XFEM method to the simulation of tensile failure in timber boards and finger-joints in a glulam strength model

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Numerical strength models for glulam have played an important role in the certification and standardization of glulam of different species [1]–[3]. A key aspect of such models—although normally not referred to as such—is the chosen failure criterion which determines the bending strength of the simulated beams. In the past, different simplified (brittle) failure criteria, based i.a. on the Weibull weakest-link theory, have been used to model both, failure of the wood and finger-joints (e.g. in [1], [2], [4]). Fracture mechanics, due to its inherent rather high computational demand and associated complexities, has been left out of such models until recently. Investigations on crack propagation on finger-joints in glulam beams using fracture mechanics was studied i.a. by 5, but it were 6 who applied this concept to a glulam stochastic strength model. For this, a finite element (FE) model with quasi-brittle failure behavior was developed, using a softening curve for the stress-displacement relationship and fracture energy. The results of the model indicated a much better representation of the size effect observed in experimental tests as compared to simply applying a brittle criterion, especially for smaller cross-sectional depths between 100 mm and 600 mm. This model applies the fracture criteria at the material level of each finite element, which, contrary to surface approaches (e.g. cohesive zone), makes the parameters—in this case the fracture energy, G_f—more sensible to the mesh size.

The relatively recent development of the extended finite element method (XFEM) and its implementation in commonly used FE software, has added one more option to be considered for the modelling of fracture mechanics problems (linear and nonlinear). The main advantages of this method, among others, consist on a mesh independence regarding the location of the crack, while allowing for surface-to-surface damage criteria (similar to a cohesive zone). These aspects, added to a simple implementation from the user's perspective, makes this method worthy of consideration for glulam strength models.

As a part of a research project dealing with the development of a glulam strength model for hardwoods, the applicability of XFEM to the simulation of tensile failure in board and finger-joint segments was performed. It was found that the method produces good results, comparable to experimental tests in glulam beams, where the size effect is well represented. A parametric analysis was performed to observe the effects of mesh size and G_f on the computed bending strengths. It was found that a mesh size of 1/3 of the lamination thickness, t (for an investigated t = 20 mm) was a good compromise between accuracy and solving time. An increase in the fracture energy of the finger-joints from 6 J/mm^2 to 20 J/mm^2 produces a somewhat linear increase in the characteristic bending strength, $f_{b,k}$, of (from 35.7 N/mm^2 to 41.2 N/mm^2) for a small beam depth of 100 mm.

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