Numerical model of glulam beam delamination in dependence on cohesive strength

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Abstract

This paper presents a finite element method attempt to predict progressive delamination of glue laminated timber beam through cohesive layer strength. There were used cohesive finite elements, quadratic stress damage initiation and mixed mode energy release rate failure criteria. Finite element damage was equal to element stiffness degradation until it achieved 1%. Timber material was considered to be elastic-ideally plastic to enable unlimited strains after reaching bending limit. Laboratory tests are not included in this paper, however, they are planned in the near future.

Keywords: progressive delamination, glue laminated timber, crack propagation, glue cohesive fracture

1. Introduction

Progressive delamination in real structures has a diverse influence on a construction. It may lead to stiffness and composite strength reduction or on the contrary may cause stress relief and delay of the total failure of the composite. It confirms the importance of choosing a suitable glue for each laminated structure.

2. Numerical model formulation

Figure 1 presents three point bending test model. Load is applied as constant vertical displacement of the steel roll. Horizontal degree of freedom of the upper roll is blocked. The beam is simply supported by two other steel rolls near the ends. Friction coefficient between steel and wood is μ=0.5, as it is specified in the literature.

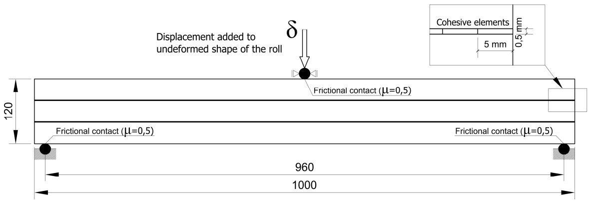

Figure 1: Three layer glue laminated timber beam model

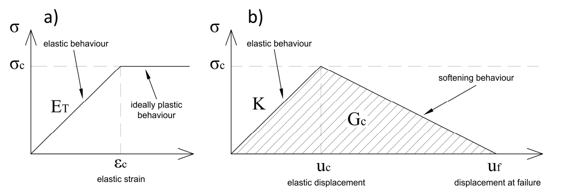

Figure 2: Material models - a) timber (simplified), b) cohesive

Thickness of a single timber plank is the value taken from a real glue laminated timber beams and is equal to 40 mm. Timber class is T14 (C24) as the producer maintain. Figure 2a) presents a simplified elastic-ideally plastic model of the timber material.

Thickness of a glue layer was defined as 0.5 mm. Figure 2b) presents cohesive elastic-softening material model [1]. Cohesive penalty stiffness depends on laminated timber parameters. Its value must be high enough to prevent from artificial stiffness influence of cohesive elements on the whole model [2]. Penalty stiffness of cohesive may be defined as:

$$K = \alpha \frac{E_T}{h_T} \qquad (1)$$

where α=50, E_T - Young modulus of glued timber planks, h_T - single timber plank thickness

Damage initiation quadratic stress criterion for plane stress:

$$\left(\frac{\sigma_x}{\sigma_{Ic}}\right)^2 + \left(\frac{\tau_{xy}}{\tau_{IIc}}\right)^2 = 1 \qquad (2)$$

Mixed mode model introduced by Benzeggagh and Kenane (BK) damage evolution criterion for plane stress [3]:

$$G_c = G_{Ic} + \left(G_{IIc} - G_{Ic}\right)\left(\frac{G_{IIc}}{G_{Ic} + G_{IIc}}\right)^{\eta} \qquad (3)$$

Table 1: Material parameters applied to model [4,5]

	Timber T14 (C24)	Polyurethane cohesive	Epoxy cohesive
FE dimension [mm]	5×5	5×0.5	5×0.5
$f_{m,T}$ [MPa]	24	-	-
$E_{T/c}$ [GPa]	11	0.6	2.6
K [GPa/mm]	-	13.75	13.75
σ_{Ic} [MPa]	-	1.3	2.4
τ_{IIc} [MPa]	-	1.3	2.4
G_{Ic} [J/m^2]	-	587	690
G_{IIc} [J/m^2]	-	1437	1690
η	-	1.8	1.8

To provide proper elements failure it is required to meet the following requirements of elements length for each mode [6,7]:

$$l_e \le \frac{l_{Ic}}{N_e} \quad and \quad l_e \le \frac{l_{IIc}}{N_e} \qquad (4)$$

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Basing on cohesive zone theories and modelling guidelines [6,7] cohesive zone length for Mode I and Mode II may be written as:

$$l_{Ic} = ME_c \frac{G_{Ic}}{\sigma_{Ic}^{\ 2}} \quad \text{and} \quad l_{IIc} = ME_c \frac{G_{IIc}}{\tau_{IIc}^{\ 2}}, \tag{5}$$

where M is a parameter that depends on cohesive zone theory, in this case M=0.31 (Irwin's theory).

Since it is recommended to use symmetrical mesh grid in symmetrical tasks, there was assigned mesh as Figure 3 shows.

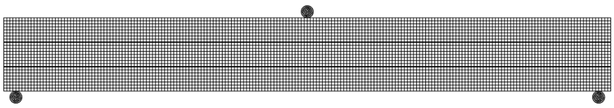

Figure 3: Symmetrical mesh grid of the FEA model

3. Results and discussion

Nonlinear numerical simulation of three point bending test showed various relationships between vertical displacement and bending stress in dependence on different glue application, as Figure 4 presents.

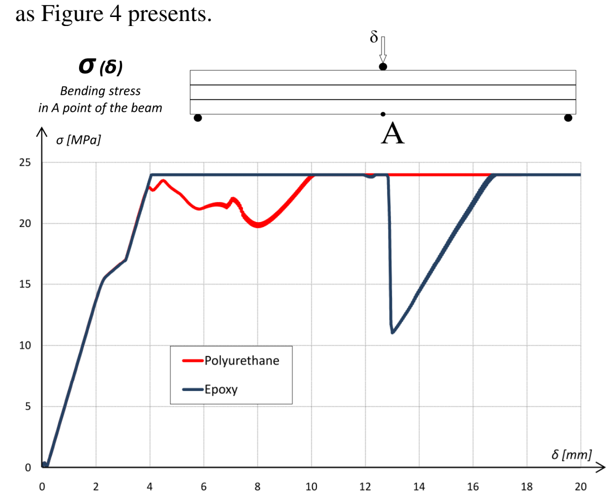

Figure 4: Bending stress - vertical displacement relation

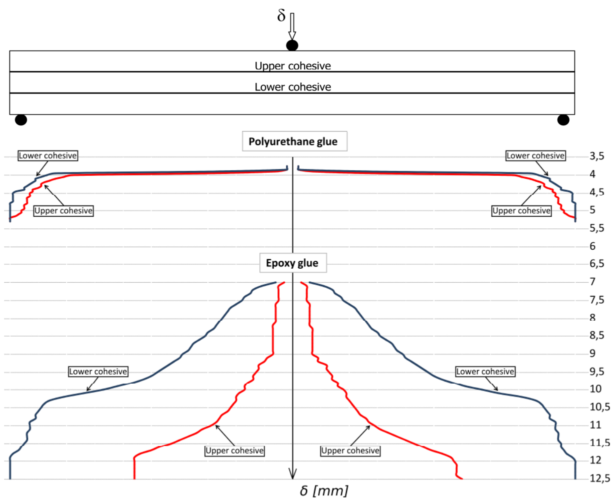

Figure 5: Cohesive crack propagation - displacement relation

Crack propagation of two different glue types in dependence on vertical displacement increment is presented in Figure 5.

Numerical model reveals complexity of stress distribution during delamination process as it is shown in Figure 6.

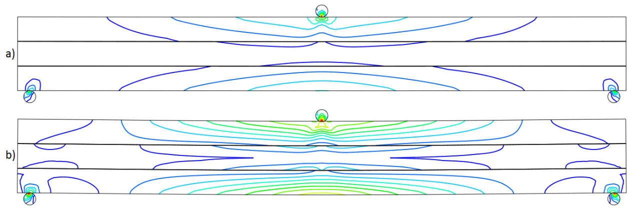

Figure 6: Huber - Mises stress isolines plot, a) before delamination, b) during delamination

4. Conclusions

In case of polyurethane glue it was observed that cohesive cracking starts earlier than in epoxy glue and leads to delay of timber bending fracture.

Beam delamination with polyurethane glue starts earlier and proceeds much faster than in epoxy. It is caused by polyurethane weaker strength in Mode I and Mode II as well as much smaller energy release rate through softening response than for epoxy.

The general purpose is to create best reality fitting crack model for glue laminated timber beams. Because of that there are planned several different types of laboratory tests in the near future.

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