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Flexural analysis of laminated solid wood beams with different shear connections

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HIGHLIGHTS

- Flexural analysis of laminated wood beams was performed.
- Experimental tests were carried out on the laminated wood beams.
- Beams with rigid and elastomeric adhesives, and screws were considered.
- Analytical and numerical (finite element) models were also applied.
- Experimental tests, analytical and numerical calculations were compared.

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ABSTRACT

The paper discusses the mechanical response of laminated solid wood beams with different shear connections. Experimental, analytical (gamma method) and numerical (finite element analysis) procedures were performed to estimate the effect of shear connections on the stiffness and the failure capacity of laminated solid wood beams. The 4-point bending tests were carried out on the simply supported laminated wood beams with rigid adhesive bonding, on laminated wood beams with elastomeric adhesive bonding, on screw-laminated beams (with vertical and inclined screws) and laminated beams without bonding. The results obtained from the experimental tests, and the analytical and the numerical test calculations were analysed and compared. These results show that the flexural stiffnesses of inclined screw-laminated wood beams and of laminated beams with elastomeric adhesive bonding are similar. Both stiffnesses are up to twice the amount of that of vertical screw-laminated wood beams. However, the stiffness of the laminated beams with rigid adhesive is even fifty per cent higher than that of the previously mentioned two similar stiffnesses.

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1. Introduction

Structural components which are fabricated by gluing and/or fastening individual dimensional timbers are referred to as laminated assemblies. Forces between members are usually transferred through lap joints, either by adhesives and/or by laterally loaded dowel-type fasteners, such as nails, bolts, dowels and screws. Several authors have extensively studied the performance of multi-layer glued beams. The results show that the strength and stiffness of laminated beams depend on many factors, such as the bonding process [1,2], the curing process [3,4], the viscosity of the adhesive [2,5], the moisture content of the wood [6,7], the temperature [8] and different types of wood and adhesives [9,10]. Analytical and numerical studies have also been done on mechanically jointed laminated beams, e.g. the nonlinear analysis of multilayered horizontal nail-laminated wood beams by Bohnhoff [11]. A complete overview of fasteners on the European market and their load-carrying capacities is available in the European Standards EN 912 [12] and EN 13271 [13].

Laminated solid wood beams are most frequently used in the post-frame building industry and in cases when the structural timber is shorter than the span. Since the laminated beams should be able to resist the design load, the composite action has to be determined. The latter increases with the increase of the rigidity of the connection between the lamellas, e.g. by using more screws or a stiffer glue. The way to increase the stiffness of the screw-laminated beam without increasing screw density or size is to add a rigid or elastomeric adhesive between the layers. Unlike rigid adhesives (epoxy), elastomeric adhesives are not as rigid as pure wood. Under the applied load, the elastomeric adhesives

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continually creep. Recently, a number of investigations have been performed in this area. e.g. The state of the art on mechanical properties of pure wood adhesives was discussed by Stoeckel et al. [14] and Vallée et al. [15]. The flexure response of horizontally glued laminated rubber wood using polyvinyl acetate adhesive with different lamina thickness was presented by Nadir and Nagarajan [16], while the structural performance of glued laminated bamboo beams was addressed by Sinha et al. [17].

A comparison between test results of connections with inclined screws and those with fasteners loaded perpendicular to their axis was presented by Bejtka and Blass [18]. A proposal for design rules for single-shear joints with inclined screws was introduced in Refs. [19,20]. The method for calculating the load-bearing capacity and the stiffness of screws placed in an inclined position with respect to the shear plane was proposed by Tomasi et al. [21]. The implementation and validation of this method was presented in Refs. [22,23]. The evaluation of the bending tests on composite glulam–CLT beams connected with inclined screws was presented by Jacquier and Girhammar [24,25]. A comprehensive state-of-the-art report on self-tapping screws and threaded rods as reinforcement for structural timber elements is given in Ref. [26].

However, the direct comparison of flexural stiffness properties between different adhesive and mechanically jointed laminated wood beams have not yet been presented. For this purpose, simple 4-point bending tests on glue-laminated wood beams (with rigid and elastomeric adhesive bonding), screw-laminated beams (with two different screw patterns for vertical and inclined screws) and stacked-beams (simply sitting on top of each other without bonding) were performed and are now introduced in this paper. The analytical method was also used to calculate the effective bending stiffnesses of these glue and screw-laminated beams. The flexural stiffnesses were obtained experimentally and analytically for different types of laminated beams. In this way, the given results were directly compared. Finally, a nonlinear finite element analysis (FEA) was performed to verify the deflections and stresses in the laminated beams.

2. Experimental program

The aim of the experimental program was to evaluate the effect of the shear connections of the laminated timber beams on both the deflection and the ultimate moment of resistance. In this experimental program, 21 timber beams were tested with a four-point bending test:

- 1 series of 3 solid wood beams to determine the timber properties,
- 7 series of 21 laminated beams with various shear connections:
  - o 6 series with 4 different shear connections (a rigid adhesive, an elastomeric adhesive, an vertical screws with 2 different patterns and inclined screws with 2 different patterns),
  - o 1 series without any shear connection.

In addition to the 4-point bending tests, three tensile and three lap shear tests were also carried out to verify the basic properties of the two different adhesives.

2.1. Verification of the basic properties of the wood and adhesives

Spruce wood (Picea Excelsa) was used in this research. It is one of the most commonly used materials in the construction industry. Since the wood is orthotropic material it requires a number of properties for its characterization. A single series of bending tests was conducted on the spruce wood material in order to verify its bending modulus. Three individual solid beams (to be used for lamellas) with cross sections of 50 × 30 mm^2 were used for individual 4-point bending tests. The tests were carried out on a ZWICK/Roell Z020 testing machine, rated to 20 kN, under cross-head displacement control. The material used in the bending tests was designed according to the EN 408 standard [27] with a total length of 1000 mm and a span of 900 mm. The load (two point forces) was applied 300 mm from each support, see Fig. 1. The wood mean density was measured at 410 kg/m^3, which is in accordance with the EN 384 standard [28]. The average modulus of elasticity of the wood was determined to be 12 GPa. This data was obtained from the load-deflection curve and a regression analysis. According to the European strength class system, the strength class of timber C30 was defined.

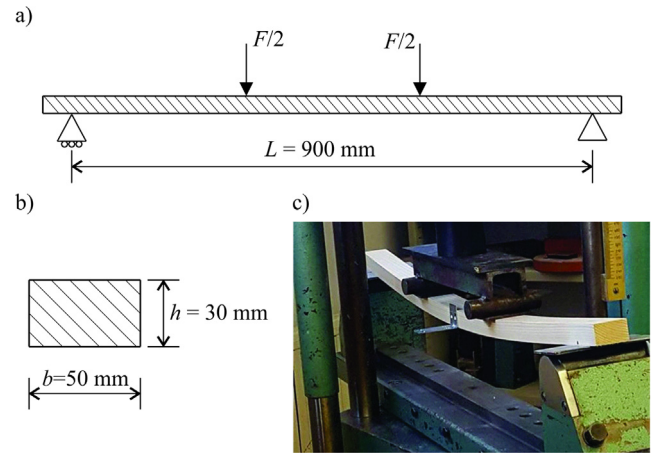

Fig. 1. Bending test of the solid wood beams: (a) The static system, (b) The vertical cross-section, and (c) Testing.

Rigid and elastomeric adhesives, which are normally recommended for wood surfaces, were used for the laminated wood beams. The rigid adhesive proposed was a two-component epoxy adhesive, while the elastomeric adhesive was a water-based adhesive made from a combination of water, polymers and additives.

Tensile tests were made on the adhesives in order to determine their elastic properties. These tests were performed in accordance with the EN ISO 527-1 [29] and EN ISO 527-2 [30] standards, which apply to both plastics and adhesives. The wood samples were tested at a speed of 1 mm/min to simulate quasi-static loading. During testing, the loads and displacements of the cross-head were continuously measured until failure occurred on the sample.

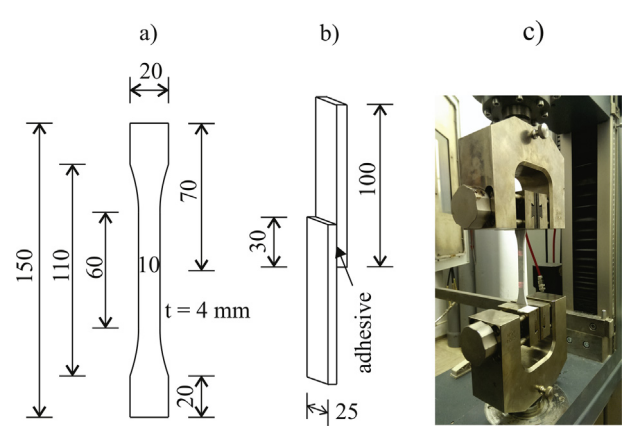

Fig. 2. Tensile and lap shear tests: (a) Sample for tensile test, (b) Sample for lap shear test, and (c) Testing.

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