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Finite Element Simulation of Four Point Bending of Laminated Veneer Lumber (LVL) Arch

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Abstract : This paper describes non-linear finite element simulation of laminated veneer lumber (LVL) under tensile and shear loads that induce cracking along fibers. For this purpose, we use 2D homogeneous orthotropic constitutive model of tensile and shear fracture in timber that has been recently developed and implemented into ATENA® finite element software by the authors. The model captures (i) material orthotropy for small deformations in both linear and non-linear range, (ii) elastic behavior until anisotropic failure criterion is fulfilled, (iii) inelastic behavior after failure criterion is satisfied, (iv) different post-failure response for cracks along and across the grain, (v) unloading/reloading behavior. The post-cracking response is treated by fixed smeared crack model where Reinhardt-Hordijk function is used. The model requires in total 14 input parameters that can be obtained from standard tests, off-axis test results and iterative numerical simulation of compact tension (CT) or compact tension-shear (CTS) test. New engineered timber composites, such as laminated veneer lumber (LVL), offer improved structural parameters compared to sawn timber. LVL is manufactured by laminating 3 mm thick wood veneers aligned in one direction using water-resistant adhesives (e.g. polyurethane). Thus, 3 main grain directions, namely longitudinal (L), tangential (T), and radial (R), are observed within the layered LVL product. The core of this work consists in 3 numerical simulations of experiments where Radiata Pine LVL and Yellow Poplar LVL were involved. The first analysis deals with calibration and validation of the proposed model through off-axis tensile test (at a load-grain angle of 0°, 10°, 45°, and 90°) and CTS test (at a load-grain angle of 30°, 60°, and 90°), both of which were conducted for Radiata Pine LVL. The second finite element simulation reproduces load-CMOD curve of compact tension (CT) test of Yellow Poplar with the aim of obtaining cohesive law parameters to be used as an input in the third finite element analysis. That is four point bending test of small-size arch of 780 mm span that is made of Yellow Poplar LVL. The arch is designed with a through crack between two middle layers in the crown. Curved laminated beams are exposed to high radial tensile stress compared to timber strength in radial tension in the crown area. Let us note that in this case the latter parameter stands for tensile strength in perpendicular direction with respect to the grain. Standard tests deliver most of the relevant input data whereas traction-separation law for crack along the grain can be obtained partly by inverse analysis of compact tension (CT) test or compact tension-shear test (CTS). The initial crack was modeled as a narrow gap separating two layers in the middle the arch crown. Calculated load-deflection curve is in good agreement with the experimental ones. Furthermore, crack pattern given by numerical simulation coincides with the most important observed crack paths.

Keywords : compact tension (CT) test, compact tension shear (CTS) test, fixed smeared crack model, four point bending test, laminated arch, laminated veneer lumber LVL, off-axis test, orthotropic elasticity, orthotropic fracture criterion, Radiata Pine LVL, traction-separation law, yellow poplar LVL, 2D constitutive model
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