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CHARACTERIZING INFLUENCE OF LAMINATE CHARACTERISTICS ON ELASTIC PROPERTIES OF SINGLE-LAYER IN CROSS LAMINATED TIMBER

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ABSTRACT: Cross laminated timber (CLT) has potential for load transfer in two directions when loaded in out-of-plane direction. The properties of CLT panels are influenced by the properties of their layers. Layer properties are influenced by their laminates' material and structural characteristics. In order to make effective use of CLT's potential it is necessary to understand the effects of laminate properties on the performance of the final product. This paper presents the approach and outcomes of an on-going study dealing with the evaluation of material and structural characteristics of laminates and their effects on CLT's overall characteristics using modal testing. Characteristics of "homogenized" layers and CLT panels were evaluated in modal and static testing. Relationships between laminate characteristics and the overall CLT performances were established.

KEYWORDS: Cross laminated timber, Modal testing, Two-way bending, Elastic properties

1 INTRODUCTION

Cross laminated timber (CLT) is an engineered wood product made from layers of timber pieces. The layers are glued together at 90 degrees to adjacent layers. As a result of the alternating grain direction of the adjacent layers, CLT shows not only material dependent anisotropy, but also structural anisotropic behaviour. The layered glue-up forms a stiff and strong plate-like structure, similar to reinforced concrete slabs. CLT shows potential for two-way resistance action and therefore an economical use in floor construction. Current design procedures for CLT under out-of-plane loading however are based on one-dimensional beam models. This does not utilize the full potential of CLT panels. Two-way plate models based on finite element (FE) analysis or advanced laminated plate theory can predict normal and shear stress distributions, as well as deflection of CLT panels under transverse loading. These models have the potential to be adopted for CLT design use. The structural properties of CLT are strongly influenced by the build-up, the thickness and the properties of the layers in the structure. A major challenge for using these models is the determination of input properties for individual layers, especially in the direction transverse to the grain of the laminates. The structural properties of a layer are mainly influenced by the elastic properties of the used laminates as well as the laminate aspect-ratio (width to thickness), their growth ring orientation and the existence of edge-gluing between adjacent laminates. The objective of this study is to develop the relationships between layer characteristics and equivalent elastic properties for input into two-way plate models.

2 METHODOLOGY

Wooden boards, mainly spruce with various growth ring patterns were conditioned to a moisture content of 13%. The boards were sized to constant length, width and thickness. The modulus of elasticity of boards and their shear modulus were determined by use of a modal testing technique as described by Chui and Smith [1] and Chui [2]. In order to obtain the elastic characteristics of the boards, the first and second natural frequencies in free-free support condition had to be determined. Based on the laminates natural frequencies, their dimensions and density, elastic modulus of elasticity and the shear modulus were evaluated and recorded.

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The boards were sorted into different groups with similar mean elastic properties, and growth ring orientation (flat-sawn, quarter-sawn and about 45°). Laminates were cut out of the boards, all laminates cut from one group had the same width and thickness. Between the different groups the aspect ratio (width to thickness) varies. Three different laminate widths were cut from the boards, 120mm, 76mm and 32mm, while keeping the thickness constant. The aspect ratios of the laminates are about 8:1, 5:1 and 2:1. The boards within a group were glued together to form fully-edge-glued (FEG) and semi-edge-glued (SEG) single-layer panels using a two component structural polyurethane polymer adhesive. FEG-layers are formed by laminates glued together over the whole length of the laminates. SEG-layers are formed by laminates glued together with a minimum local glue spots. SEG-layers are used to simulate non-edge-glued layers, the minimum local glue area is needed to enable the structure to be tested as a layer. Also in practice, even in non-edge-glued product, it is reasonable to assume that a small quantity of glue will be squeezed to the edge from the laminate faces due to the press pressure. The grouping of the laminates by elastic modulus, shear modulus, aspect ratio and growth ring pattern led to "homogenized" layers with similar laminate characteristics. These single-layer plate specimens were tested to determinate their elastic parameters using modal test methods by Sobue and Katoh [3] and Larsson [4], and static tests based on ASTM test methods [5,6]. In the method by Sobue and Katoh [3] the layer is simply supported on one edge while the other edges have free boundary conditions. Three elastic constants, namely the modulus of elasticity parallel to the grain (E_{11}), the modulus of elasticity perpendicular to the grain (E_{22}) and the in-plane shear modulus (G_{12}), were calculated based on three natural frequencies and simple equations. The method by Larsson [4] is based on free-free boundary conditions and has no closed form solution. Here E_{11}, E_{22} and G_{12} were determined in an iterative process using FE analysis. In the process, the three elastic constants were adjusted successively until experimental and analytical natural frequencies matched. The results from the modal test methods were compared with each other and results from the static tests. The analysis of the test data led to the development of relationships between laminate characteristics and elastic properties of the single-layers.

The single-layers were face-glued to form squared 3- and 5-layer CLT panels. The properties of the CLT panels were evaluated using the modal test methods by Sobue and Katoh [3] and Larsson [4], and static tests based on ASTM test methods [5,6]. In addition static two-way plate bending test were performed on the CLT specimens. Strain gauges were used to measure strains in selected layers and locations. The measured deflection and the evaluated stress distribution were compared with those predicted from FE model. The input properties of the FE model were based on properties of the corresponding single-layers.

3 RESULTS AND CONCLUSION

At the time of the submission of this abstract the elastic characteristics E_{11}, E_{22} and G_{12} of the FEG single-layer panels have been evaluated using modal testing methods [3,4], static tests based on ASTM test procedure [5] have been performed for E_{11} and E_{22}. From the comparison of the evaluated FEG single-layer properties E_{11} with averaged laminated properties ($E_{average}$) for various combinations of laminate aspect ratio and growth ring orientation it can be seen that laminates with a small aspect ratio and a growth ring orientation of 45° lead to an increase of E_{11}, quarter-sawn laminates lead to a reduction of E_{11} in comparison to $E_{average}$. The E_{11}-value determined by static tests showed good agreement with the ones from modal tests, the average deviation is 6%. For the E_{11}-value determined by Larsson [4] average deviation to static test based E_{11}-values is about 1.4%. Results for the other elastic properties show higher deviation in both comparisons. The gluing process of the SEG single-layers is in progress. It is expected that results from the modal and static test of the all single-layers and CLT panels can be included in the final paper.

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