ABSTRACT: Models for estimation of structural properties of glued laminated timber (glulam) are generally based on the relationship between properties of the individual laminations and properties of the glulam. In this investigation, a recently presented machine strength grading method based on laser scanning of fibre direction fields was applied for determination of axial modulus of elasticity (MOE) profiles along glulam laminations. These profiles were then used to calculate edgewise bending MOE ($E_B$) profiles of glulam beams. The objectives were to investigate the relationship between position of bending failure and position of lowest $E_B$ value along investigated beams, and the relationship between the mentioned $E_B$ value and bending strength of the beams. It was found that both relationships were rather weak, whereas local bending MOE determined in accordance with EN 408 was predicted with high accuracy on the basis of $E_B$ profiles.

KEYWORDS: laser scanning, fibre angle, glulam, laminating effect, tracheid effect

1 INTRODUCTION

Most methods applied for machine strength grading of timber are based on limited statistical relationships between strength and so called indicating properties (IPs). The most frequently used IPs are averaged measures of modulus of elasticity (MOE) determined by means of either flatwise bending or axial dynamic excitation. However, by means of a recently presented new grading method [1] the variation of edgewise bending MOE ($E_B$) and axial MOE ($E_a$), respectively, can be determine with a very high resolution along timber pieces.

Glued laminated timber (glulam) laminations are typically machine strength graded timber $\leq$ 50 mm thick. The grading implies that laminations are assigned to grades with different structural performance in terms of tensile strength, tensile stiffness and density. A distinguishing feature of glulam is the so called laminating effect, which means that the bending strength of a beam is higher than the tensile strength of its outer laminations. This is explained by three different characteristics: 1. edgewise deflection of a lamination in a beam is restrained by the bonding, 2. effects of a local defect are smeared out resulting in material homogenization, and 3. defect zones in a lamination are reinforced by adjacent laminations.

In the grading method presented in [1], laser scanning of fibre angle fields on board surfaces, and axial dynamic excitation, are applied to determine profiles of $E_a$ and $E_B$, respectively, with a resolution of about 1 mm in longitudinal board direction. For glulam laminations, being loaded mainly in the axial direction, the $E_a$ profile is of main concern. If this profile is determined for each lamination in a glulam beam before gluing, the axial stiffness variation is known in the entire beam. By means of stiffness integration over the beam’s cross-section, the edgewise bending MOE profile ($E_B$) along the beam can be calculated. The purposes of this research were to investigate to what extent the longitudinal position of bending failure in a glulam beam corresponds with the position of the lowest $E_B$ value found along the beam, and to determine the coefficient of determination ($R^2$) between the lowest $E_B$ and bending beam strength ($\sigma_m$), the latter determined using beam bending tests based on the European Standard EN 408 [2].

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2 MATERIAL

The study comprised 450 Norway spruce laminations of two strength classes (LS15 and LS22) glued into 50 beams of five different types, see Figure 1. Ten beams of each type were investigated. The nominal lamination dimension in the beams was 33×90 mm.

![Figure 1: Beam lay-up types A–E (length L in mm)](image)

3 MOE PROFILES AND MEASURES

Stiffness profiles in terms of $E_B$ of the 50 beams were calculated for different moving average lengths and displayed in MATA LB® diagrams, see example in Figure 2a which exhibits the section between the two point loads of a four-point beam bending test set-up based on EN 408 [2]. The predicted position of failure, i.e. the position of the lowest $E_B$, and the actual failure position is highlighted.

![Figure 2: Beam no. E10, mid-section, EN 408 bending test: a) MOE profiles, determined for a moving average length of 150 mm; $E_S$ for lamination at compression edge (blue curve), $E_A$ for lamination at tension edge (red curve), $E_B$ for entire beam (black curve), and b) beam failure](image)

According to EN 408, the local edgewise MOE, $E_{loc}$, is determined in the mid span of a four-point bending test, over a length of five times the beam’s depth. Here, $E_{loc}$ was compared with an MOE value denoted $IP_{5h}$ and determined as the average of $E_B$ over the same length. As shown in Figure 3, the relationship was very strong.

![Figure 3: Relationship between local MOE ($E_{loc}$) based on EN 408 and MOE calculated as averaged IP over a length of five times the depth of the beam](image)

4 RESULTS AND CONCLUSIONS

The possibility of predicting the failure position was evaluated using a criterion such that if the actual failure occurred within ±75 mm from the predicted point of failure, the failures were considered to be coinciding. In spite of the high resolution of evaluated $E_B$ profiles, the failure position was correctly predicted in only about a third of the 50 beams. Regarding the coefficient of determination ($R^2$) between the lowest $E_B$ and bending strength ($\sigma_m$), it was generally found to be poor compared to the $R^2$ values that can be achieved when the method described in [1] is applied for sawn lumber. The results are explained by the fact that the laminating effect of glulam is very strong. A typical example is shown in Figure 2a. However, $E_B$ profiles can be applied to accurately predict the local edgewise bending MOE based on EN 408, which indicates that high-resolution information about MOE distribution in glulam beams can be applied for development of glulam models based on e.g. the finite element method and fracture mechanics.

REFERENCES
