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An innovative method based on grain angle measurement to sort veneer and predict mechanical properties of beech laminated veneer lumber

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HIGHLIGHTS

- The local grain angle can be measured using light scattering for beech veneer.
- Mechanical properties of Laminated Veneer Lumber (LVL) can be predicted using local grain angle measurements.
- LVL production could be graded on the basis of local grain angle.

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ABSTRACT

This study proposes an innovative model based on local grain angle measurements to predict the modulus of elasticity of LVL made from beech. It includes a veneers sorting method industrially compatible thanks to its low computational time. For this study 41 LVL panels were prepared from 123 beech sheets of veneers. Local grain angle was obtained with a two dimensional scanner and veneer density was measured. Several models based on these measurements have been developed and their ability to predict the modulus of elasticity of LVL panels have been compared. The model based only on local grain angle measurements have been proven more efficient than models taking into account the veneer density. The proposed method can be used to sort veneer during the peeling process and grade the production of LVL panels to optimize their mechanical properties even for low-quality veneer.

1. Introduction

In recent years, interest in the use of beech as a raw material in engineered wood products for structural purpose has increased in Europe, particularly in France and Germany, where these renewable resources are available and not used to their fullest extent. Laminated veneer lumber (LVL) is made from rotary peeled veneers that have been dried and then glued together. The grain direction of the layers is mainly oriented in the same direction and parallel to its length [1]. This product has exhibited superior mechanical properties in axial bending tests compared to solid wood even when manufactured from lower-grade logs [2,3]. In LVL, the defects are randomly distributed throughout the cross-section, which prevents the concentration of stresses at specific locations. Moreover, using low-grade veneers in the inner plies can reduce the processing costs without significant decrease in mechanical properties. Furthermore, the aesthetic value of the final product is conserved by using free-defect veneers only for visible sides. This approach is well known for drawing full benefit from second quality wood.

The mechanical properties of LVL can be affected by several factors such as juvenile wood [4,5], jointing method [6], lathe checks [7,8], load direction [9,10], veneer thickness [11] or silvicultural practice [12].

To predict the mechanical properties of LVL some non-destructive testing (NDT) methods were studied in the literature to evaluate the bending properties. A study on red maple [13] showed that the flexural properties of LVL can be predicted using ultrasonic method and suggested that the performance of LVL can potentially be enhanced through ultrasonic rating of individual veneer sheets. The same conclusions have been made in a study for LVL made of *Schizolobium parahayba* [14]. Another study conducted on southern pine [15] used ultrasonic method and transverse vibration and showed that the prediction of the bending stiffness using these methods is less accurate and reliable for LVL compared to solid wood. Pu and Tang [15] also found a significant effect of veneer grade on the modulus of elasticity (MOE) of LVL. The efficiency of ultrasonic methods for two different species has also been discussed by de Souza et al. [16] and it has been shown that

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Nomenclature

List of main symbols

ρ_{veneer} veneer density
$\theta(x,y)$ local grain angle
$E_{veneer}(x,y)$ local modulus of elasticity of veneer
$\bar{E}_{veneer}$ averaged local modulus of elasticity of veneer
$E_{glob,exp}$ global modulus of elasticity assessed by static bending
$E_{ply}(x,y)$ local modulus of elasticity of veneer with variables parameters
$E_{mean}(x)$ averaged local modulus of elasticity along the width of veneer
$E_{glob,mod}(\rho)$ MOE calc. on basis of the proposed model taking into account only the density
$E_{glob,mod}(GA)$ MOE calc. on basis of the proposed model taking into account only the grain angle
$E_{glob,mod}(\rho+GA)$ MOE calc. on basis of the proposed model taking into account both the density and grain angle
ρ_{panels} panels density
$\bar{E}_{panel}$ average of $E_{veneer}(x,y)$ of the three constitutive plies
$\bar{E}_{panel-opti}$ average of $E_{ply}(x,y)$ of the three constitutive plies with optimal parameters
$\bar{\theta}_{abs,veneer}$ average value of local grain angle in absolute value

the correlation with the MOE was significant for *Pinus kesiya* and that there was no correlation for *Pinus oocarpa*.

The wood material presents a very high variability arising from several factors. In particular, many studies have shown the existing correlation between density and mechanical properties [17–19] of sawn timber.

For clear wood in general, the MOE in fibers direction can be considered to depend on density and microfibril angle (MFA) [20]. However, beech wood is a very homogeneous specie regarding the density: its coefficient of variation (CV) can vary between 4% and 6 % only [21,22]. Therefore, the level of determination of MOE variation which have a CV up to 16% [22], by density is expected to be low. The variation in specific modulus (MOE divided by the density) due to tree growth (juvenility, ring width, tree slenderness, reaction wood...) is on the contrary similar to other species and driven by MFA variations.

At the timber scale, several other studies [3,23,24] report the same tendencies regarding the variation of density (CV from 5% to 6%). More than 1800 timber beams of beech were characterized in [23], the coefficient variation of MOE was found to be up to 20% (mean value equal to 14 100 MPa) for a coefficient variation of density equal to 6% (mean value equal to 670 $kg.m^{-3}$). Another study on compression and tension properties of beech lamination [24] stated that due to its low variation (CV of 5%), density could not contribute significantly to the strength and stiffness prediction. This study also showed the poor correlation existing between density and modulus of elasticity in both tension and compression tests, with a coefficient of determination found between the density and the modulus of elasticity lower than 0.06.

For beech LVL, the variation of density according to [3] is also low (CV lower than 5%). In addition, the authors didn't even tried to grade the veneers according to density based on previous study [25] stating that there were no relationship between density and strength properties for beech wood.

Moreover, local singularities such as knots and grain angle have a strong influence on the mechanical properties. Indeed, the authors of [24] finally concluded that strength and stiffness are mainly determined by the knot area ratio. Several studies have focused on the measurement of the local grain angle on timber [26–28]. The potential of the grain angle measurements has also been studied for strength grading of timber and it has already proven to be efficient to predict mechanical properties [29–32]. Other studies [33,34] have also shown the potential of grain angle measurements to predict mechanical properties of glulam beam made of spruce. To the best knowledge of the authors there are no investigations carried out on local grain angle measurement to predict LVL mechanical properties.

The main purpose of the present study is to develop a method based on grain angle measurement to predict the modulus of elasticity of LVL made of beech. The second goal is to assess the efficiency of local grain angle measurements to grade beech LVL.

2. Materials and methods

2.1. Veneers production

Two green logs of beech from two different trees (*Fagus Sylvatica L.*) were selected from the plantation site of Cluny (Burgundy, France) for their high knotiness. They were soaked at 60° C for 24 h and then rotary peeled using a light packaging scale lathe (SEM S500 - knife length 900 mm) equipped with an angular pressure bar. The veneer's thickness was set to 2 mm and the compression rate was 5% of veneer thickness (a gap of 1.9 mm between cutting face and pressure bar nose). Subsequently the veneers were dried in a vacuum dryer with heating plates to limit waviness and to reach about 12% moisture content. Afterward, dried veneers were cut to $600 \times 75\ mm^2$ and conditioned in a climatic chamber for 72 h at a temperature of 20 °C and 65% of relative humidity. After conditioning, each veneer was weighed to obtain their average specific density ρ_{veneer}. In total, 123 veneers were prepared for this study.

2.2. Grain angle measurement

Each veneer sheet was characterized with an optical scanner designed to measure the local grain angle (BobiScan, LaBoMaP). The grain angle is measured by projecting a line of laser spots on the surface of the veneer. As a result of wood anisotropic light diffusion properties, an elliptic pattern oriented parallel to the projection of the fibers axis can be observed on veneer surface. The grain angle can be obtained with Principal Component Analysis applied on each ellipse binarized image. The grain angle evolution over the whole veneer surface is obtained by illuminating the surface with several laser spots along a line (Fig. 1a). The grain angle measurement has been conducted only on one face of each veneer (it has been considered that the grain angle is the same through the section since the thickness is only 2 mm). An example of the grain angle measurement is shown in Fig. 1(b) where the resolution is 1 mm in x direction and 5 mm in y direction. As a final step, a linear interpolation of the raw data was conducted to obtain a regular grid (Fig. 1(c)). This accurate technique allows to observe the strong deviations of the fibre direction around knots.