INFLUENCE OF VENEER LATHE CHECKS ON THE MECHANICAL PROPERTIES OF LVL

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ABSTRACT

Laminated veneer lumber (LVL) is a high-performance engineered wood product made of several wood veneers bound together mostly in grain direction. Veneers are obtained thanks to peeling process. This cutting process induces lathe checks of the veneer with variable depth and spatial frequencies. In this work, we studied the influence of lathe checks on the mechanical properties of LVL thanks to a finite element model of LVL beams made of checked veneers. The checks were modelled as free spaces in the cross-section. Several typical check depths and frequencies were compared, with the beam tested edgewise or flatwise. The results show that the longitudinal modulus of elasticity and the shear modulus in flatwise bending are marginally affected by checking, while the shear modulus of the LVL beam is significantly reduced in edgewise bending if the check depth is important. This phenomenon is due to high shear deformations in the edgewise bending case, because checks are mainly horizontal in this state. Therefore, the check depth may also affect the resistance of LVL in edgewise bending, thus experimental testing of this assumption will be done.

Keywords: Laminated veneer lumber; lathe checks; shear modulus; mechanical properties.

INTRODUCTION

The peeling process induces lathe checks in the veneers (1-3). Thibaut and Beauchene (4) proposed a simplistic cutting force model able to describe chip formation and lathe check generation (Figure 1). Depending on several parameters as veneer thickness, wood density and wood temperature, the energy required to produce the veneer during cutting can be lower by splitting than by shearing. Indeed, the cutting geometry generates a traction stress field which favours check opening (see Figure 1). For given cutting conditions and homogenous woods as poplar, beech or birch, the thicker the veneers, the larger the check depth and the interval between checks (5-8). Lathe checks depth can be limited thanks to a pressure bar (9, 10). This system compresses wood just ahead the cutting edge (see Figure 1), so that lathe check formation is limited.

Laminated veneer lumber (LVL) is an engineered wood product made of several veneers bound together mostly in grain direction. It is used in many structural applications because of its great mechanical properties. Indeed, LVL is an up-and-coming opening for engineered wood products, as shown by the recent industrialization of beech LVL in Europe (11). The modulus of rupture in bending (MOR) of LVL is higher than solid wood with less variations because of the even distribution of natural defects such as knots, slope of grain or splits (12-14). Using thick veneers allow to produce LVL with less plies, thus the production time and glue consumption are shorter, but the MOR can be lowered (15-17).

If authors agree on the negative influence of veneer thickness on the bending MOR, its influence on others mechanical properties is not yet clarified in the literature. Furthermore, the influence of lathe checks on LVL mechanical properties is rarely studied, while thicker veneers also have deeper checks (5-7). For plywood panels, it has been shown that lathe check frequency, depth and orientation influence the shear strength and MOR (18, 19). For LVL, some authors found that the modulus of elasticity (MOE) is slightly lowered by lathe checks (16, 17), but others found that there was no significant effect. Indeed, Hoover et al. (20) showed that the number of layers in hardwood LVL had no significant effect on the MOE or on the shearing strength. Conversely, Ebihara (15) found that shear modulus and shear strength parallel to grain of both edgewise and flatwise LVL decrease while veneer thickness increases. But, in terms of MOE in three-point bending tests there were no clear differences. In the present work, it is proposed that some of this contradictory results, especially concerning shear, can be explained by different depth or frequency of lathe checks.

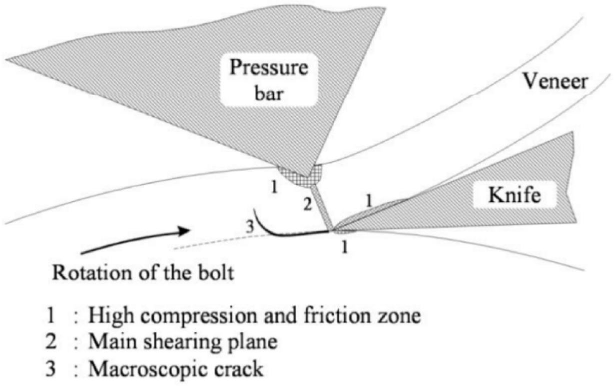

Figure 1: Main mechanical phenomenon during the peeling process (inspired by Thibaut and Beauchene (4)).

The approach proposed is based on the use of a finite element model in which lathe check parameters are known, which enables to be free from the variability of checking due to wood heterogeneity. However, the input data of the model as material properties or check frequency are obtained from experimental measurements of the literature.

MATERIALS AND METHODS

Experimental data for model inputs

The model inputs (lathe checks geometry, material properties) are based on experimental results of the literature. Several studies deal with lathe checks frequency and depth according to peeling settings or wood material (5-10). Pot et al. (10) measured checks depth and interval of 3 mm beech veneer peeled with compression rates of 0% (no pressure bar), 5%, 10% and 15%. The compression rate of the pressure bar is defined as the radial penetration of the pressure bar into the wood divided by the nominal thickness of the veneer. Check spatial frequency increases from 297 to 410 m^{-1} (Figure 2c) for compression rate between 0 and 15% (10). While check frequency increases, the mean check depth decreases linearly. The equation of this linear relationship is:

$$d\% = -0.3493\, f + 161.5 \qquad (1)$$

Where d% is the mean check depth (% of thickness, which is a constant of 3 mm here), and f is the check frequency. This linear relationship is used later in this paper for modelling purposes.

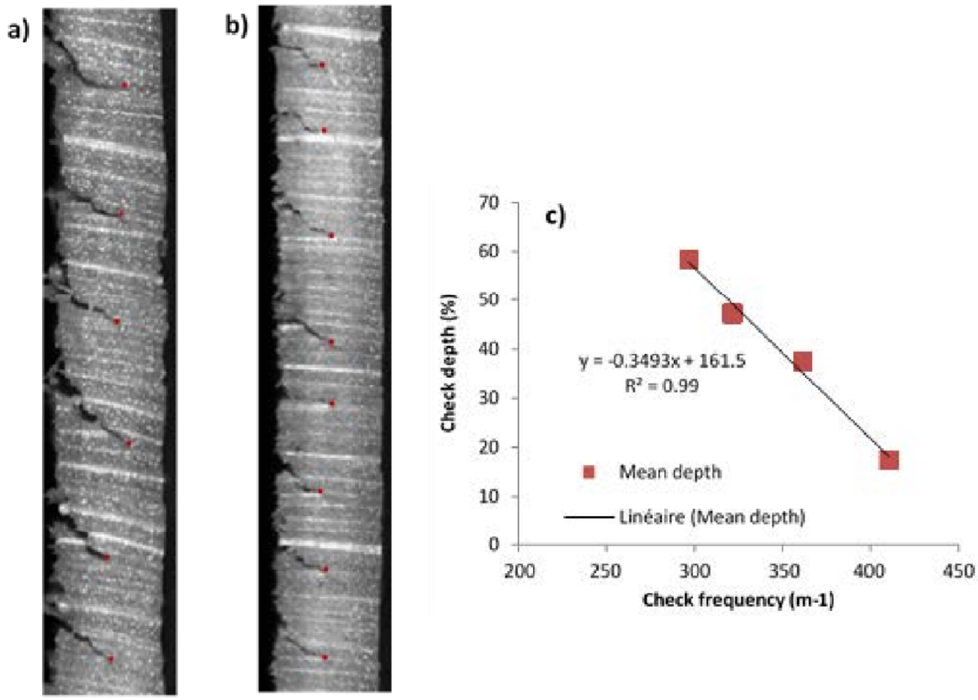

Figure 2: SMOF (5) images of checked beech veneers obtained with compression rates of the pressure bar of 0% (a) and 10% (b). The red dots show the position of the tip of each check. (c) Mean check depth according to check frequency of veneers obtained using different compression rates of the pressure bar.

The mechanical properties used in the model are those given by Guitard (21, Table 9). Wood is considered as a homogenous, elastic, and orthotropic material. The assumption of homogeneity is justified for woods as beech or poplar which are particularly homogenous woods (22, 23). The present paper focuses on beech, but the conclusions might be the same for other homogeneous wood species.

Table 9: Mechanical properties of beech wood (at 12% moisture content according to (21)) that are used in the finite element model. R radial, L longitudinal, T tangential.

Wood mechanical properties	Beech
Young modulus in R direction E_R (MPa)	2040
Young modulus in T direction E_T (MPa)	867
Young modulus in L direction E_L (MPa)	14100
Shear modulus in R-T plane G_{RT} (MPa)	500
Shear modulus in T-L plane G_{RL} (MPa)	1850
Shear modulus in R-L plane G_{TL} (MPa)	980
R-T poisson ratio ν_{RT}	0.726
L-R poisson ratio ν_{LR}	0.365
L-T poisson ratio ν_{LT}	0.464
T-R poisson ratio ν_{TR}	0.309

R-L poisson ratio ν_{RL}	0.053
T-L poisson ratio ν_{TL}	0.029
Density ($kg.m^{-3}$)	710

Finite element model

The FEM of the checked LVL beam is built in ANSYS® Mechanical, Release 14.0 program with 3-D quadratic solid elements. Wood is considered as a homogenous, elastic, and orthotropic material (data Table 1). An elementary pattern of checked veneer is defined thanks to a given interval between checks and veneer thickness (Figure 3a). The width of the checks is taken equal to 7% of the interval in its larger part. This width is divided by 3 at the half depth of the check, and then the width of the check decreases until check's tip. The pattern of Figure 3a is repeated in the height and the width of the beam in order to obtain a 20 mm x 20 mm cross-section (Figure 3b). This cross-section is in accordance with NF B 51-016 (24) standards for bending tests on small clear specimens. Notice that the interlayered glue bond is not modelled, which means that the glue bond is considered to behave as wood material. The section of Figure 3b is extruded in the longitudinal direction to build a beam of 240 mm long.

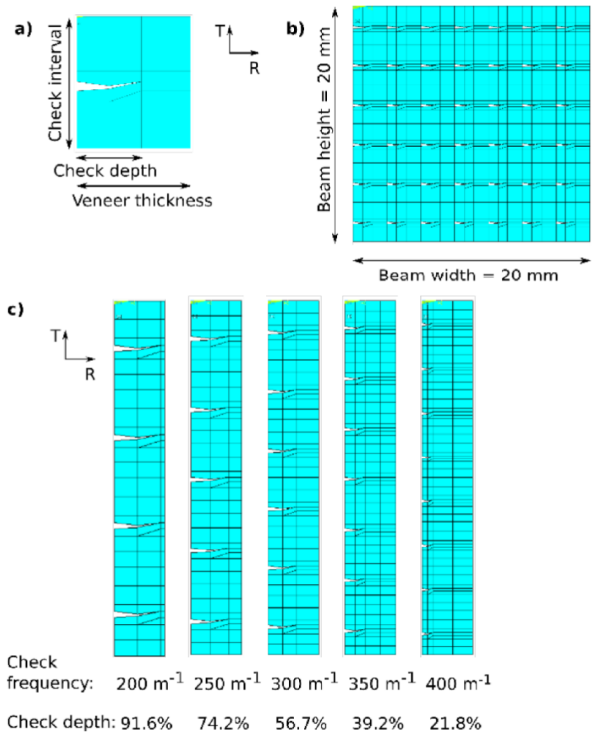

Figure 3: Finite element model of checked LVL beam tested in edgewise condition. (a) Basic pattern; (b) beam cross section (check frequency 300 m^{-1}); (c) finite element model of the five different checked veneers used in the LVL beam model with different check frequency and check depth that respect the linear relationship of equation 1.

As shown in Figure 3b, the check depth and the interval between checks are constant for a given LVL beam. It is assumed that these parameters are linearly dependent by application of Equation 1. This modelling enables to highlight the effect of lathe check depth and frequency regardless of their natural variability shown previously. However, because of the imposed cross-section of 20 mm x 20 mm for the beam and because of the basic pattern defined in the model, the number of veneers and the number of intervals must be integers. Thus, veneer thickness cannot be 3 mm as in experimental works, but is defined as 2.86 mm in order to have a whole number of veneers in the cross-section (7 veneers). It is assumed that this difference of 4.6% in veneer thickness does not influence the relationship between lathe check frequency and mean check depth. According to this relationship, the possible check frequencies range between 200 and 400 m^{-1} (4 to 8 intervals in the width of the LVL beam), since the range of possible check frequencies is limited by the depth (between 0% and 100% of veneer thickness). The models of the five possible checked veneers are presented in Figure 3c. A model of a homogeneous beam with clear wood without any checks has also be done but not it is presented in Figure 3c.

Calculations of elastic mechanical properties

It has been showed in the literature that the application of conventional Timoshenko bending theory lead to erroneous shear moduli when measuring the deflection of a beam subjected to static bending (10, 25). This is the reason why in the present study a vibrational method is applied.

Brancheriau et al. (26, 27) showed that the longitudinal MOE and the shear modulus can be computed from the flexural vibration frequencies in free-free condition. Indeed, Brancheriau et al. (27) give the following solution of the equation of motion of a vibrating beam at the first order:

$$\frac{E_X}{\rho} - \frac{E_X}{KG_{XY}} x_n = y_n \qquad (2)$$

Where E_X is the longitudinal modulus, ρ is the density, K is the shear factor ($K = 5/6$ for a rectangular cross-section), G_{XY} is the shear modulus in the XY plane, x_n and y_n are parameters that depend on the vibrational mode frequency (see 27 for detailed expression). By plotting y_n against x_n for different vibration modes, a linear regression can be performed and the MOE and shear modulus are found. The deviation of this equation is generally less than 1% if the length-to-depth ratio is between 10 and 20 (it is 12 in the present work).

This methodology is applied in the present work after having performed a modal analysis in ANSYS®. The first, second and third flexural vibration frequencies in free-free condition were computed for the different modelled beams, both for the edgewise and flatwise bending direction.

RESULTS AND DISCUSSION

Modulus of elasticity

The MOE of LVL is presented in Figure 4 against check depth or lathe check spatial frequency, for beam in edgewise or flatwise condition. The MOE decreases linearly with check depth to reach a maximum reduction of 2.6% in comparison with clear wood for flatwise LVL with lathe checks depth of 91.6%. As a result, the bending modulus of LVL is not highly influenced by lathe checks because they affect only marginally the inertia of the beam. These results are in accordance with experimental studies which did not find clear difference in the MOE of beams made of different veneer thicknesses (i.e. different check depth and frequency) (15, 20).

For each check frequency, there is a relative difference lower than 0.5% between the MOE in flatwise or edgewise loading. This very small difference is most likely due to the deviation of the solution of the equation of motion (26), which may be different between edgewise and flatwise bending because shear moduli are different.

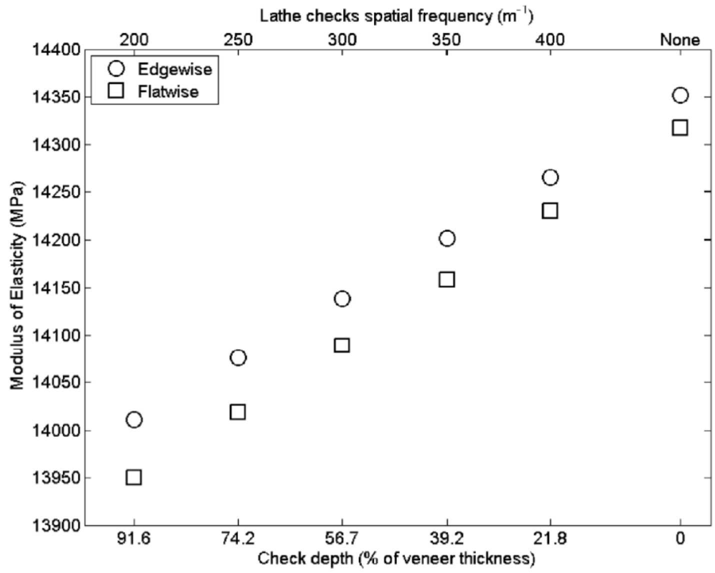

Figure 4: MOE of LVL in edgewise and flatwise condition according to checks depth and frequency. A check depth of 0% corresponds to clear wood.

Shear modulus

The shear moduli of LVL are presented in Figure 5 against check depth and lathe check spatial frequency, for beam in edgewise or flatwise condition. The shear modulus which is calculated in flatwise bending (squares in Figure 5) is higher than in edgewise bending (circles in Figure 5). This is due to the difference in the material shear modulus according to loading direction (higher shear modulus in the R-L plane than in the T-L plane, cf. Table 1).

The shear modulus decreases as lathe check depth increases, with a very much higher rate in edgewise bending. In the most disadvantageous case (LVL with lathe check depth of 91.6%), the shear modulus is reduced by 2.8% in flatwise bending in comparison with clear wood, while it is reduced by 31.4% in edgewise bending. Thus, the shear modulus of LVL is significantly affected by lathe checks depth in edgewise bending, which is already the bending condition for which the shear modulus of the wood is the lowest. The shear modulus of the LVL beam with the deepest checks can be as low as 690 MPa in edgewise bending that is 2.7 times lower than the same LVL beam in flatwise bending (1850 MPa).

This behavior can be explained by shear strains that are more important in edgewise bending because checks are horizontal, thus they are more subjected to shear than in flatwise bending, for which checks are vertical. The Figure 6 illustrate this explanation, showing high concentration of deformation in edgewise bending near the tip of the checks, which does not exist in flatwise bending. Furthermore, deep checks induce higher concentrations of shear than small checks, thus the shear modulus is lower with deep checks. This effect is amplified by the fact that in this model checks are inline in radial direction (Figure 3b), which is the most disadvantageous case for shear. One can note that for a different check geometry, for example more curved checks, the results may be different as curved checks may be more subjected to shear if tested in flatwise bending, which must result in a higher influence on the LVL shear modulus in flatwise bending.

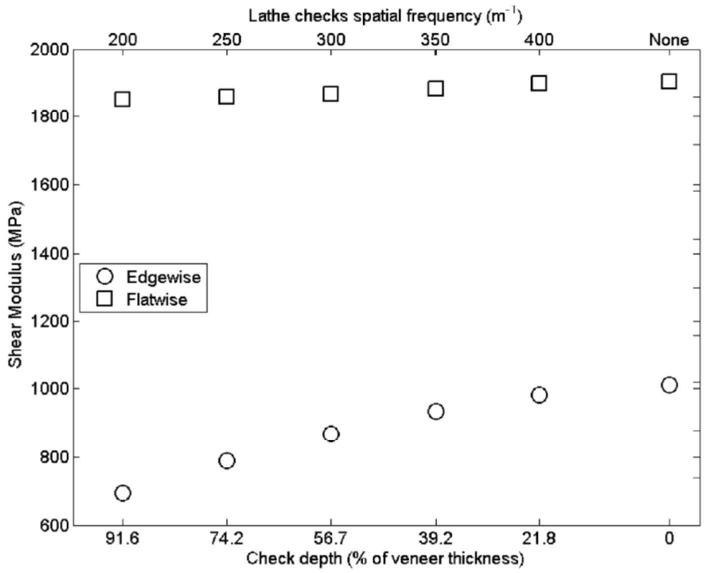

Figure 5: Shear modulus of LVL in edgewise and flatwise condition according to checks depth and frequency. A check depth of 0% corresponds to clear wood.

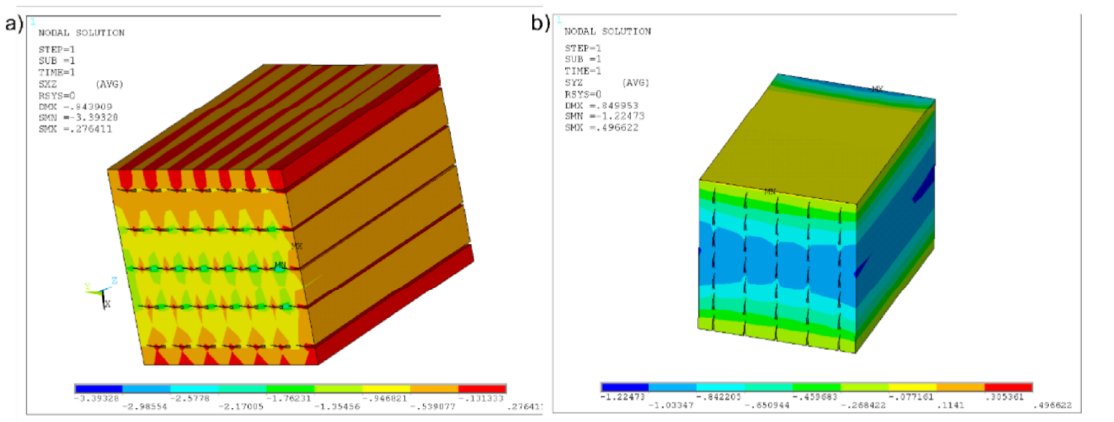

Figure 6: Shear deformations obtained in a 3-point bending numerical test for a checked LVL in edgewise condition (a) and flatwise condition (b) (same load, 74.2% check depth).

CONCLUSIONS

In the present work, a FEM of an LVL beam with checked veneers of a constant thickness is proposed. The model is based on the assumption of a periodic distribution of checks, with a linear relationship between check depth and frequency. This methodology lead to a better understanding of the influence of lathe check depth and frequency on the mechanical properties. The longitudinal MOE and shear modulus are calculated by using a modal analysis.

The results of the model show that neither the MOE of LVL nor the shear modulus in flatwise bending is significantly affected by lathe checks (less than 2.8% decrease). Conversely, the shear modulus in edgewise bending can be reduced up to 31.4% in comparison with clear wood. The shear modulus for the LVL beam with the deepest checks can be as low as 690 MPa in edgewise bending, which is 2.7 times lower than the same LVL beam in flatwise bending (1850 MPa). As a result, the shear deformations of LVL in edgewise bending may be of concern for designing purposes.

The low shear modulus in edgewise bending is due to the repartition and shape of checks in the model that induce higher shear deformations when checks are vertical than when they are horizontal. This deformation concentration may be also a stress concentration zone that could induce rupture, so the relationship between shear modulus of LVL and its MOR should be studied. Further numerical simulations need to be performed to study the influence of the check pattern, check distribution, or veneer thickness on the shear modulus. Experimental validation of these numerical results is also in progress.

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