



Strength modelling of Laminated Veneer Lumber (LVL) beams



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HIGHLIGHTS

- A mechanical model to predict the strength of LVL beams is developed.
- The model is calibrated and validated against experimental tests.
- The model accurately predicts test results with a low CoV of 0.10.
- The application of the model is illustrated on new juvenile hardwood LVL beams.
- New LVL beams have design strengths superior to commercially available LVL beams.

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ABSTRACT

This paper develops a mechanical model to accurately predict the strength of Laminated Veneer Lumber (LVL) beams, and illustrates its applications to numerically predict the strength distribution of LVL beams manufactured from veneers rotary peeled from early to mid-rotation subtropical hardwood plantation logs. This resource is not traditionally used in the manufacturing of commercialised LVL beams. In the first part of the paper, the model is described, calibrated against experimental results performed on 8-ply LVL beams and then verified against experimental results performed on 13-ply LVL beams. Results show that the model is able to accurately reproduce the experimental results, both on flat and edge bending, with an average prediction-to-experiment ratio of 1.0 and a relatively low coefficient of variation of 0.10. A sound prediction of the non-linear behaviour of the beams before failure was also observed. In the second part of the paper illustrating the applications of the model, the mechanical properties of veneers analysed by the authors in a previous work are used as input values in the numerical model to predict the strength of six commercially available LVL beam sizes, manufactured from early to mid-rotation subtropical Gympie messmate (*Eucalyptus cloeziana*), spotted gum (*Corymbia citriodora*) and southern blue gum (*Eucalyptus globulus*) plantation veneers. The design strength (5th percentile) of the beams, obtained by Monte Carlo simulations, is reported and found to range from 32.3 MPa to 97.2 MPa, depending on the quality of the veneers used and the beam size. The LVL beams have design strengths comparable to, and in some cases up to 2.5 times higher than commercially available softwood LVL beams, making them attractive structural products. The strength variability is also reported in the paper for developing probability-based limit state design criteria in future studies.

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1. Introduction

Veneer Based Composite (VBC) structural products, such as plywood or Laminated Veneer Lumber (LVL), are commonly used in timber constructions. Their advantages over sawn structural timber lie in their higher capacities and more reliable mechanical

properties, and capability of spanning longer distances [1]. With the increasing number of tall timber buildings being built worldwide, their use is expected to further grow. When new VBC products, such as those manufactured from new timber species for instance, are introduced on the market, expensive experimental tests must be carried out to determine their strength and stiffness distributions, therefore ensuring reliable design properties.

If an accurate numerical model could be developed and combined with an established probabilistic database of the mechanical properties of the individual veneers, it would represent a valuable

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tool in predicting these distributions and optimising the use of the veneered resources. The model would allow for instance to either cost-effectively select the type of veneers to be used in the manufacture of structural products with targeted strength or predict the capacity of products manufactured from new resources. The database on the individual veneers must probabilistically quantify their strength from characteristics which can be and are frequently measured in line during manufacturing, such as the veneer dynamic Modulus of Elasticity (MOE) and total knot area ratio (tKAR). Very little research aiming at modelling the strength of VBC structural products parallel to the grain exists in the literature and it mainly focuses on strand based composites [2–5]. Other numerical models have been mainly developed for sawn timber [6–12] or glulam beams [13–15]. No model currently exists to mechanically predict the strength of veneer-based structural products based on the veneer properties.

This development of this numerical tool is currently undertaken by the authors to ultimately predict the strength distributions of veneer-based structural products manufactured from veneers rotary peeled from early to mid-rotation subtropical hardwood plantation logs. This resource represents a new opportunity to the timber industry and not traditionally used in the manufacture of commercial structural products. In this attempt, this paper (i) extends the numerical mechanical models developed for Glulam [13] and sawn timber [7] beams to predict the strength of Laminated Veneer Lumber (LVL) beams based on the known mechanical properties of the veneers, and (ii) illustrates the applications of the model in the development of new products by numerically predicting the strength distributions of LVL beams manufactured from the previously mentioned new feedstock. An established database of the mechanical properties of the veneers [16] is used for purpose of the latter item. Specifically, the numerical model, combined with the Monte Carlo simulation method, is used to estimate the statistical characteristics of six commercially available LVL beam sizes, manufactured from four grades of early to mid-rotation subtropical Gympie messmate (*Eucalyptus cloeziana* – GSM), spotted gum (*Corymbia citriodora* – SPG) and southern blue gum (*Eucalyptus globulus* – SBG) plantation veneers.

The paper is articulated around five main stages. First, a background of the overall research undertaken is presented and the established database on the probabilistic mechanical properties of the veneers of the three studied species used through the paper is summarised. Second, the principles behind the numerical model are described and hypotheses made are justified. Third, the model is calibrated against a first series of four-point bending tests performed on LVL beams for which the dynamic MOE, tensile and compressive Modulus of Rupture (MOR) of each plies of the beams were assessed. Fourth, the accuracy of the model is further validated against a second independent series of four-point bending tests performed in McGavin, et al. [17]. Finally, using the validated numerical model, the statistical characteristics of the strength of the six commercially available LVL beam sizes are predicted and reported. The design strength (5th percentile) and the statistical data of each investigated case are given and discussed.

The focus of this paper is on the strength modelling of the LVL beams. While the ability of the model to predict the overall linear and non-linear behaviour of the beam up to failure is verified in the aforementioned third stage, the use of the model to predict the static beam stiffness is outside the scope of the paper. Indeed, the dynamic MOE of the veneers, measured in line during manufacturing through a resonance method and used as model input herein, is different to the static one. This effect is due to the viscoelastic nature of the wood [18,19] and also likely from hot pressing the veneers and gluing them during the manufacturing process. Unpublished tests performed by the authors tend to show that

these two effects result in the dynamic MOE of the veneer being about 10% lower than its static one within a glued LVL panel. Therefore, while using the veneer dynamic MOE in the model does not change the stress distribution in the beam, it does not result in an accurate determination of the static bending stiffness needed for design purpose. More investigations, outside the scope of this paper, need to be performed to quantify the actual relationship between the static MOE of glued veneer-based products manufactured from the three investigated species and their veneer dynamic MOE. Consequently, the model would in that case also offer the possibility to accurately predict the static bending stiffness of LVL beams.

2. Incentive and database on resources used

2.1. General

Incentives to use juvenile hardwood plantation logs in the manufacture of VBC products is observed in Australia [17,20–22], but also in New-Zealand [23], South America [24] and Europe [25]. These studies show that the use of juvenile hardwood logs results in attractive VBC structural products, yet the number of tests was limited and further studies are required to accurately define their mechanical performances. In this context, this paper results from a collaborative project between universities and the Queensland government aiming at thoroughly quantifying the expected strength of VBC products manufactured from logs sourced from hardwood plantations, either primarily established for pulpwood production or for high quality solid wood markets. In the latter type of plantation, only high quality trees are allowed to mature and the logs originate from the lower quality trees (for instance, those that are crooked, smaller or have too many branches) removed in an operation referred to as “thinning”. In the former type, the logs originate from the plantations being clear felled with no thinning or pruning. In both cases, the trees are typically harvested between 12 and 15 years after establishing the plantation, are about 15–30 cm in diameter at breast height and referred to as “early to mid-rotation” trees. The manufacturing industry is challenged with the use of these resources which display significant mechanical properties variations, between and within trees. Because of the high proportion of defects in the resources (knots, gum veins, grain deviation, etc.), the new structural products are expected to have a reduced mean strength and larger variability in their mechanical properties than the conventional LVL and plywood products manufactured from mature trees of the same species, to a degree currently unknown.

In a first stage, a database on the mechanical properties of veneers recovered from early to mid-rotation hardwood plantation logs of three species (GSM, SPG and SBG) was established in [16]. The database allows probabilistically predicting the compressive and tensile strength of the veneers from their dynamic Modulus of Elasticity (MOE) and total knot area ratio (tKAR), which can be measured in line during manufacturing. The trees used to establish the database and in this study, were 10–12, 13–16 and 12–15 years old, and had an average diameter at breast height over bark (DBHOB) of 20.6, 30.6 and 31.9 cm, for the SPG, SBG and GSM logs, respectively [26,27].

This paper represents the next stage of the project where a numerical model is developed and its potential is illustrated by determining the strength distribution of LVL beams manufactured from the three species investigated in the overall project. As veneers recovered from these three species are used through this paper to first calibrate and validate the model, and then illustrate its applications, it is important to understand their mechanical

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