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Visual stress grading of fibre-managed plantation Eucalypt timber for structural building applications

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HIGHLIGHTS

- Fibre-grown *E. nitens* was processed to produce sawn timber for structural uses.
- A profile of material properties was created for the recovered timber boards.
- The most important visual characteristics of the boards were identified.
- The impact of the visual characteristics on MOE/MOR of the boards was assessed.
- Three structural grade groups were proposed for the resource based on the results.

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ABSTRACT

The aim of this study was to examine the impacts of visual characteristics, strength-reducing features (SRFs), and basic density on the mechanical properties of fibre-managed plantation Eucalypt timber to create effective structural grade groups. It is the intension that the results found in this study can lead to the development of a visual stress grading method for fibre-managed plantation timber in the future and influence the development of new applications for the resource in structural elements for the built environment. The plantation specie investigated in this study was *Eucalyptus Nitens*–390 sawn timber boards. The most important visual characteristics and SRFs likely to influence the mechanical properties of the boards were visually identified and measured before the boards were divided into designated groups for sampling. The impacts of the visual characteristics, SRFs, and basic density of the boards within each group on modulus of elasticity (MOE) and modulus of rupture (MOR) were determined using four-point bending test. The statistical analyses suggest three structural grade groups can categorise the resource. Strong correlations were found between MOE, MOR, and basic density with the visual characteristics and SRFs of the boards in the three grade groups.

1. Introduction

The reliability and design flexibility of timber-rich construction makes wood products an attractive option for designers and builders. It is widely recognised that timber is:

- Environmentally friendly because wood is biodegradable, recyclable, and renewable [11,14].
- A sustainable building material that is widely available in nature as long as the harvested trees are replaced by new plantings [29].
- Very low in production energy compared to other building materials such as concrete, steel, and aluminum [32].
- Structurally effective due to its high strength-to-weight capacity ratio [10,29].
- An effective, natural insulator because of its porous structure [21].
- Light and easy to work with [39].
- Naturally beautiful with a featured pattern that adds character and warmth.

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With the increased effectiveness and sophistication of high-mass laminated timber products, demand for timber solutions in different structural applications has rapidly increased in recent decades – especially in building construction [39]. However, timber's availability for construction is also an important issue. Using fast growing plantation species like Eucalypts on short rotation harvest cycles could be a viable and necessary contemporary solution to this issue. Eucalypts are the main plantation hardwood species in the world and most are planted and managed for fibre production. While efficient for fibre production, the forestry practices used in a fibre-focused management regime generally produces small logs of low-grade wood. It is challenging to find a practical way to use fibre-managed Eucalypt in the timber and construction industry as the sawn timber and veneer recovered from this resource is young, highly variable, and has substantial strength-reducing features (SRFs) such as knots and drying defects [26,8,6]. These can limit its use in structural applications [12].

The Australian National Construction Code (NCC) regulates all structural applications in buildings and consequently establishes the minimum 'fit-for-purpose' requirements for structural timber. To satisfy the NCC's requirements, structural timber elements have to comply with either the requirement of the relevant structural grading standards or have independent engineering certification of their structural performance. For hardwood, the relevant structural grading standard is Australian Standard (AS) 2082 (Timber – Hardwood – Visually stress graded for structural purposes, [2]). Grading under AS 2082 [2] is based on the visual examination of the SRFs and other attributes of each board and allocation to it of a structural grade. Combining this structural grade with the species' typical mechanical properties assigns a stress grade to the board. In practice, this method assumes a direct correlation between the assessed visual SRFs of the board and its structural properties, and is based on correlations established on testing relationships between the visual characteristics and mechanical properties of mature wood from native forests. By contrast, fibre-managed Eucalypt plantations are quickly grown and often harvested at 15–20 years old. They yield logs and recovered timber that contain a high percentage of SRFs and juvenile wood. As a result, they are likely to have physical and mechanical properties that are completely different in value and in the relationship between SRFs and structural capacity from those of mature native forest wood of the same species. Given this, the methods for visual stress grading of hardwood in the current standard may not be relevant to such a resource. In this process, the origin of boards (plantation or native forests) and the specific requirements in the target application for the boards need to be taken into account. Boards may be graded and sold as individual commodity items for use in an unknown application in buildings or graded and incorporated into a purpose design component. Parts of these issues have already been addressed in previous studies [16,28,23,1,31,19,24,33,13,35,25]. However, the relevance of visual stress grading of timber to fibre-managed plantation species is still unknown.

The goal of this study was to investigate the effects of visual characteristics and SRFs on the mechanical properties of timber boards recovered from fibre-managed plantation *Eucalyptus nitens* (*E. nitens*) and create effective structural grade groups that can be used to inform the development of a practical visual grading method for the resource. *E. nitens* was selected in this study as it is one of the most widely planted fast-growing eucalypt species in Australia. Due to its abundance, there is interest in developing new applications for the resource especially in the built environment. Specific objectives of the study:

- Investigated the nominal recovery rate and dressed-board recovery of fibre-managed plantation *E. nitens* – sawn, dried, and dressed using standard commercial procedures.
- Created a profile of material characteristics of fibre-managed plantation *E. nitens* by assessing the visual characteristics, SRFs, basic density, and moisture content (MC) of recovered boards.
- Categorised the boards into different groups based on their wood quality, SRFs, and other visual characteristics.
- Determined the modulus of elasticity (MOE) and modulus of rupture (MOR) of the boards from different quality groups to evaluate the correlations between the visual characteristics, SRFs, and basic density with the mechanical properties of the boards under uniaxial bending loads.
- Developed regression models to predict MOE and MOR values using the visual characteristics, SRFs, and basic density of the boards.
- Developed effective structural grade groups for the boards based on the results obtained.

2. Materials and methods

2.1. Harvesting, sawing, and drying processes

For this study, 29.30 m^3 of *E. nitens* logs were harvested from a 16 years old fibre-managed plantation on the northeast of Tasmania, Australia. The average small-end diameter of the logs was 345 mm. After harvested, the logs were sawn and the boards dried using standard commercial procedures. This ensured that the results would align to any future production system that used the same equipment suite and processes. Logs were sawn into boards of four nominal widths: 75 mm, 100 mm, 125 mm, and 150 mm, and a nominal 38 mm thickness. To maximise volume recovery rate, logs were plain sawn and the sapwood was retained. The lengths of the recovered boards varied. The average lengths by width were 4551 mm, 4391 mm, 4551 mm, and 4582 mm respectively. The boards were dried in pre-dryers for nine weeks under rack weights and then air-dried in the mill yard for three weeks. After reconditioning, they were dried in conventional kilns to a nominal MC of 12%. The rack weights were kept on the boards during the entire drying processes to decrease possible distortions in the boards due to rapid drying. The dry boards were finally square dressed to widths of 70 mm, 90 mm, 120 mm, and 140 mm, and a thickness of 35 mm.

2.2. Assessment of visual characteristics

In total, 390 boards with the four different widths were studied for a broad range of various visual characteristics and SRFs.

2.2.1. Knots and knotholes

Knots are one of the features that can significantly affect the mechanical properties of timber and wood products [18,24,17] and the dimensions of knots in the piece are one of the key factors in the current visual stress grading standards. In this study, knots with a diameter larger than 1/4 of the width of the boards were considered major knots. This boundary diameter for major knots was chosen as timber boards that have knots with diameters equal to or smaller than 1/4 of the width of the boards can still be graded as either Structural Grade No. 1 (the best grade) or Structural Grade No. 2 in AS 2082 [2]. The frequency and type of major knots were assessed in each board.

The existence of knotholes on the boards was also assessed. This criterion was mainly an indicator of the presence or absence of knotholes not their quantity or dimensions.

2.2.2. Surface checks

Surface checks with individual lengths exceeding 1/4 of the length of the boards and or surface checks with a width larger than 3 mm were examined and reported. Boards that have surface checks with a length and or a width equal to or smaller than the aforementioned values can still be graded as Structural Grade No. 1 according to AS 2082 [2] – hence, they were not considered as major surface checks in this study.

2.2.3. End splits

The length and width of end splits were measured on each board and the percentage of boards with major end splits was reported. Major end splits in this study are those that had a length larger than or equal to the width of the boards.

2.2.4. Wane

Wane is the under-bark surface of a log that appears on the edge of a sawn timber board. The amount of wane on each board was assessed and the percentage of boards with significant amount of wane was reported. Wane larger than 1/10 of the cross-sectional area, wane on the face of the boards exceeding 1/2 of the board's