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Structural behaviour of hardwood veneer-based circular hollow sections of different compactness

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HIGHLIGHTS

- Veneer-based timber compact and slender cross-sectional shapes are investigated.
- The sections were tested in bending, shear and compression.
- Bending: sudden failure of the slender sections compression fibre is observed.
- Shear: all cross-sections have similar and relatively low shear strength.
- Compression: the compact sections were ductile, the slender ones burst into strips.

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ABSTRACT

This paper presents the capacity and structural behaviour of hardwood veneer-based circular hollow sections (CHS) tested in bending, shear and compression. The sections were manufactured from early to mid-rotation (juvenile) Gympie messmate (*Eucalyptus cloeziana*) plantation thinned logs. In total twenty-one 167 mm Outside Diameter (OD) × 1.2 m long CHS were manufactured in seven sets of three nominally identical sections. Two different wall thicknesses were investigated to produce nine compact and twelve more slender cross-sections. The sections were also manufactured in three different structural grades. A sudden failure mode was observed in the compression zone of the slender sections tested in bending. In compression, the compact sections showed a ductile behaviour, while the slender sections showed a more brittle behaviour, with the sections bursting into longitudinal strips. While a relationship was observed between the bending and compressive capacities, and the structural grade, no such relationship was noticed for the shear capacity. Comparison to steel and concrete sections of similar outside diameter proved that the timber sections are the most efficient in terms of bending and compressive capacity to linear weight ratio. The timber sections fall behind their steel and concrete counterparts in terms of shear efficiency, however they still have enough shear capacity for representative structural applications.

1. Introduction

To develop a market for low-value, small diameter, early to mid-rotation (juvenile) hardwood plantation logs, veneer-based hollow sections are currently being developed in Australia [1–3], see Fig. 1. These sections have the potential to be used in structural applications [1,3] and are seen, for instance, as a potential solution for utility poles [1] and the main frame of buildings. They have the advantage of having an efficient cross-sectional shape, are sustainable [4–6], and able to be manufactured in usable lengths [2] and cross-sectional sizes that are no longer available in sawn timber.

In the literature, various hollow timber structural solutions have been investigated. They include (i) spirally winded veneer-based Circular Hollow Section (CHS) [7–9], (ii) fibre-reinforced moulded wooden tubes [10–14], (iii) octagonal tubes from composite wood flakes panels [15], (iv) nonagon tubes from knot free pine wood strips [16], (v) "wood rings" reinforced with glass epoxy [17] and (vi) LVL type CHS for temporary geotechnical soil nailing systems [18]. Commercially, veneer-based hollow timber solutions

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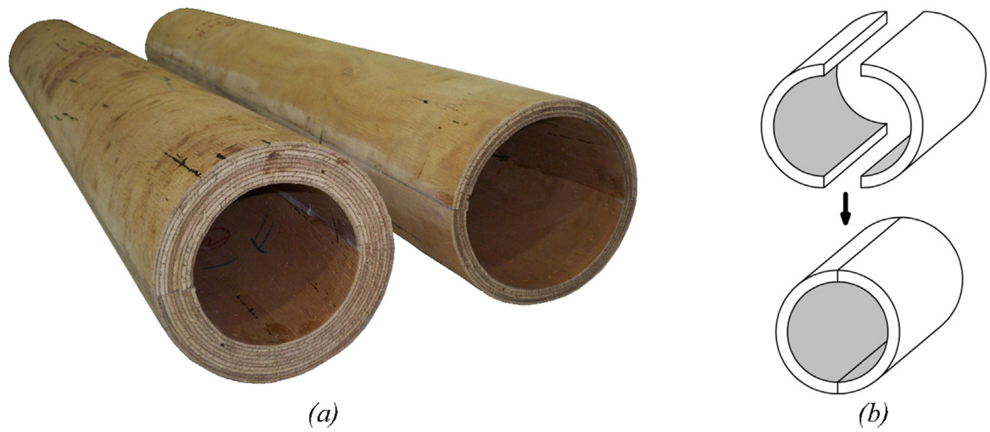

Fig. 1. (a) circular hollow section currently developed in Australia (shown for compact and slender 167 mm (OD) Gympie messmate) and (b) principle of half cross-sections butt joined together to form a complete CHS.

are also available, either limited to small diameter cross-sections (up 100 mm) [19] or short lengths (up to 1000 mm) [20].

To confidently use the new sections in structural applications, research is still needed to fully understand their structural behaviour, failure modes and reliability. In particular, bending tests performed on 145 mm Outside Diameter (OD) × 15 mm (wall thickness) Laminated Veneer Lumber (LVL) type CHS showed that the sections can experience a sudden failure in the compression zone, with the sections opening up [1]. While this failure mode has been observed in hollow trees [21], it is not typical of solid timber beams which usually reach a maximum bending moment due to tensile rupture [22]. The sudden compressive failure mode is likely attributed to the semi-compactness of the cross-section in [1] which led to local buckling and cross-section ovalisation (Brazier effect [23]). The relationship between the cross-sectional slenderness and structural behaviour requires further attention.

Consequently, the structural behaviour and failure modes of veneer-based timber CHS of various cross-sectional slenderness are experimentally investigated in bending, shear and compression in this paper. In total twelve 167 mm (OD) × 12.5 mm (wall thickness), referred to as "slender", and nine 167 mm (OD) × 25 mm (wall thickness), referred to as "compact", 1.2 m long CHS were manufactured from early to mid-rotation (juvenile) Gympie messmate (*Eucalyptus cloeziana*) plantation thinned logs. The veneer grain was orientated in the same direction and along the member longitudinal axis for all sections except for one type of the slender sections. For this section, cross-banded veneers were used in this case to potentially increase the section local buckling capacity. To study the effect of the timber elastic stiffness on the new products' structural behaviour, the CHS were manufactured in three different structural grades. The grades were solely based on the veneers' Modulus of Elasticity (MOE).

The paper initially introduces the investigated cross-sections and the associated manufacturing process. Secondly, the test setups for all investigated loading cases are presented. Thirdly, the structural behaviour, capacities and failure modes of the slender and compact sections are analysed and discussed. Finally, the performance of the studied sections is compared to similar steel and concrete counterparts.

2. Investigated cross-sections

2.1. General

In total, twenty-one nominal 167 mm (OD) × 1.2 m long veneer-based CHS were manufactured from two half cross-sections following the process described later in Section 2.2. Randomly selected nominal 1.2 m (Long) × 1.2 m (Wide) × 2.5 mm (Thick) Gympie messmate rotary peeled veneer sheets were delivered and then cut parallel to the grain direction (i.e. perpendicular to the length of the veneer ribbon) into four 300 mm wide strips. The longitudinal dynamic MOE of each veneer sheet was then measured using a non-destructive resonance method [24]. To do so, the second cut strip per veneer sheet was simply supported on rubber bands and impacted with a hammer in its longitudinal direction. The sample natural frequency was recorded using a microphone and analysed using the software BING® (Beam Identification by Non-destructive Grading) [25]. Fig. 2 shows a photo of the setup. Before assessing the dynamic MOE, the veneers were conditioned in a temperature controlled room set at 22 °C.

Based on their measured MOE, the delivered veneer sheets were divided into three stacks of equal number of veneers. This classified the veneers into three grades referred to as "Grade 1" for the lower MOE (13 GPa < MOE ≤ 19 GPa), "Grade 2" for the intermediate MOE (19 GPa < MOE ≤ 21 GPa) and "Grade 3" for the higher MOE (21 GPa < MOE ≤ 25 GPa).

The twenty-one CHS were manufactured in seven sets of three nominal identical samples. Per set, the half cross-sections of the three nominally identical CHS were manufactured from the same veneer sheets which were glued in the exact same order. Precisely, for each veneer sheet, three 300 mm wide strips out of four were used in the CHS manufacturing process. The remaining strip was used to determine the material properties of the half cross-sections as detailed in Sections 2.2 and 3.2. The seven sets consisted of:

- Three sets of nominal 167 mm (OD) × 12.5 mm (5-ply) slender CHS manufactured from Grade 1 (Set "S_G1"), Grade 2 (Set "S_G2") and Grade 3 (Set "S_G3") veneers. In these sets, the veneers' grain is orientated in the same direction and along the longitudinal axis of the section.
- One set of nominal 167 mm (OD) × 13 mm slender CHS. To potentially increase the section local buckling capacity, a cross-banded configuration was used. Four 2.5 mm thick Gympie messmate hardwood Grade 2 veneers were orientated along the longitudinal axis of the section and three 1 mm thick cross-banded softwood Hoop pine (*Araucaria cunninghamii*) veneers were inserted between the hardwood veneers to form a 7-ply configuration. This set is referred to as "S_G2_Cross".
- Three sets of nominal 167 mm (OD) × 25 mm (10-ply) compact CHS manufactured from Grade 1 (Set "C_G1"), Grade 2 (Set "C_G2") and Grade 3 (Set "C_G3") veneers. In these sets, the veneers' grain is orientated in the same direction and along the longitudinal axis of the section.