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Veneer based composite hollow utility poles manufactured from hardwood plantation thinned trees

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HIGHLIGHTS

- Experimental tests on hollow utility poles manufactured from mid-rotation hardwood plantation thinned trees are presented.
- The incentives behind the project and benefits of the proposed products are introduced in the paper.
- A simple failure mechanism model in bending of the poles is developed and compared to experimental results.
- The mechanical performance of the poles is discussed and compared to traditional hardwood poles cut from native forests.
- The required dimensions of the proposed hollow pole to replace traditional solid poles are also estimated.

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ABSTRACT

Australia's utility pole network is aging and approaching its end of life. It is estimated that 70% of the 5 million poles currently in-service nationally were installed within the 20 years following the end of World War II and require replacement or remedial maintenance. Additionally, an estimated 21,700 high-durability new poles are required each year to support the expansion of the energy network. Utility poles were traditionally cut from native forest hardwood species. However, due to agreements which progressively phase out logging of native forests around Australia, finding new sources for utility poles presents a challenge. This paper presents the development of veneer based composite hardwood hollow utility poles manufactured from mid-rotation Gympie messmate (*Eucalyptus cloeziana*) plantation thinned trees (also referred to as "thinning"), as an alternative to solid hardwood poles. The incentives behind the project and benefits of the proposed products are introduced in the paper. Small diameter poles, of nominal 115 mm internal diameter and 15 mm wall-thickness, were manufactured in two half-poles butt jointed together, using 9 hardwood veneers per half-pole. The poles were tested in bending and shear, and experimental test results are presented. The mechanical performance of the hollow poles is discussed and compared to hardwood poles sourced from mature trees and of similar size. Additionally, the required dimensions of the proposed hollow pole to replace actual solid poles are estimated. Results show that the proposed product represents a viable technical solution to the current shortage of utility poles. Future research and different options for improving the current concept are proposed in order to provide a more reliable and cost effective product for structural and architectural applications in general.

1. Introduction

Utility poles, commonly referred to as "power poles", support the energy network and therefore represent a vital part of the infrastructure in developed countries. Yet, Australia's utility pole network is aging and reaching its end of life, with 70% of the 5 million poles currently in-service nationally installed within the 20 years following the end of World War II [1]. Structural failure of one pole may have severe consequences on local communities and the economy in general.

The estimated investment required for the replacement or remedial maintenance of the aging 3.5 million Australian poles is as high as 1.75 billion Australian dollars (about 1.6 billion USD), based on an assumption of 500 Australian dollars per new pole [1]. Additionally, an estimated 21,700 high-durability new poles are required each year for extending the network and meeting energy demand, representing further investment of 13.5 million Australian dollars (about 12.2 billion USD) per year [1].

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Hardwood utility poles have been traditionally used in Australia. Compared to more intensively manufactured steel, concrete or fibreglass poles, they are still thought to be the most economical and durable solution in terms of life-cycle costs [1]. Yet, due to growing environmental awareness and concerns over the sustainability of native forestry practices, agreements which progressively phase out logging of native forests around Australia have been signed [2]. In South-East Queensland where this project is originated, the South-East Queensland Forest Agreement (SEQFA) [3] was signed in 1999 and phases out logging of native forests by 2025, giving the industry 25 years to make the transition from Crown native forests to plantations and private forests. Consequently, the shortage of utility poles is expected to increase dramatically over the next decade while the demand is expected to rise sharply [1]. Finding long-term supply solutions to enable replacement of the aging poles presents a challenge.

Various alternative solutions to solid timber poles or columns have been proposed in the literature. Adam et al. [4] analysed the feasibility, design strength and cost of hollow octagonal utility poles manufactured from composite wood flakes panels. The poles were tapered with the wall thickness decreasing with the height. Results indicated that the proposed poles were able to be cost competitive in the market place. Kyoto University has been intensively researching composite structures ranging from LVL cylinders [5,6] to spirally cylindrical laminated veneer lumbers [7–9]. The latter product is manufactured through a continuous process with veneer tapes wound around a mandrel in clockwise and anticlockwise directions to form an interlocking pattern [7]. Low quality logs were used for the veneer tapes and the distance between butt jointed veneers was found to significantly influence the strength of the product [8]. Piao [10] manufactured 1.2 m (small-scale) and 6 m (full-scale) long nonagon hollow poles from knot free pine wood strips. While full-scale poles were not tested to failure, cantilever tests performed on the small-scaled poles showed that shear failure can govern the strength of the poles. Wehsener et al. [11] have recently reported current research into fibre-reinforced moulded wooded tubes manufactured by shaping densified timber boards. The tubes have been used to support a 9 m tall wind power plant.

This paper presents tests on Veneer Based Composite (VBC) hardwood hollow utility poles manufactured from mid-rotation Gympie messmate (*Eucalyptus cloeziana)* plantation thinned trees, also commonly referred to as "thinning", a species traditionally used in Australia for poles due to its favourable natural durability and strength properties [12]. The incentives of using hardwood plantation thinned trees and benefits of the proposed products are introduced in the paper. Six small diameter poles, of nominal 115 mm internal diameter and 15 mm wall-thickness, were manufactured in short lengths of 970 mm. To determine their mechanical characteristics, four poles were tested in bending and two poles in predominant shear. Experimental test results are presented in the paper and a simple failure mechanism model in bending of the poles is also introduced and compared to experimental results. The mechanical performance of the hollow poles is discussed and compared to traditional hardwood poles of similar size cut from native forests. The required dimensions of the proposed hollow pole to replace traditional solid poles are also estimated. Future research and different options for improving the current concept are proposed in order to provide a more reliable and cost effective technical solution to the current shortage of utility poles.

Research is currently underway on best connecting short lengths of VBC products to form useable beams and columns. The determination of the mechanical characteristics (stiffness and strength) of these connections is outside the scope of the present paper. Solutions that are currently being investigated are presented at the end of the paper. Furthermore, while the current research focuses on utility poles, due the reasons presented earlier, the proposed sections can also be used for various structural and architectural applications, such as building beams and columns, or alternatives to steel street lighting and traffic light poles.

2. Economic and environmental benefits of using hardwood plantation thinned trees

In hardwood plantations grown for high-quality solid wood products, an average of 1000 stems per hectare are planted. However, only high quality trees are allowed to mature, with the lower quality trees (for instance, those that are crooked, smaller or have too many branches) removed in an operation referred to as "thinning" or "pre-commercial thinning". Typically, two main thinning operations occur. Nearly half of the trees (around 500) are cut at 1.5–3 years in the first thinning, with another 300 cut in the second thinning (mid rotation) at 10–15 years before the plantation is finally clear-felled at 25–35 years. The trees cut during the second thinning have a breast-high diameter (BHD) of about 15–30 cm, and are deemed of little or no commercial value.

To justify continued expansion of Australia's current hardwood plantation estates, it is becoming necessary to develop high value end-use products for these small logs [13], as there are no clearly identified viable markets for these resources. Pulpwood was regarded as the only large scale viable option for these logs if the plantation is in close proximity (less than 100 km) to a processing facility and/or forms part of an overall harvest scheme [13]. In more recent times, the international pulpwood market has become less attractive for Australian plantation growers. Additionally, with the uneconomical long crop rotation time of 25–35 years, the risks from fire, pests and adverse weather events increase dramatically each year while not translating into substantially higher financial returns to the grower. More than 400,000 hectares of hardwood plantations have been planted around the year 2000 and a large quantity of mid rotation thinning logs are potentially immediately available, reinforcing the need to develop a market for this type of resource [14].

Various VBC structural applications using hardwood thinning veneers have been developed at Griffith University [14] in collaboration with the Salisbury Research Facility, Queensland Government, in an effort to develop high value end-use products for these mid-rotation logs. Advantages of the new products over sawn timber sections lie with the products (i) having efficient cross-sectional shapes, (i.e. hollow for the poles presented in this paper) and (ii) being able to be manufactured in large sizes currently not available in timber, as the manufacturing process [14] allow customising the dimensions of the product to meet a desired design capacity.

A study in Israel [15] has shown that short rotation plantations, based on harvesting 50% of the slower growing trees for use in the manufacture of Medium-density Fibreboard (MDF), as pulpwood or fire wood, could provide better returns to farmers. The current project may provide financial benefits to growers by creating a value-add industry. As a result, they may realise earlier return on investment after 10–15 years, instead of the current 25–35 years (particularly if the mid-rotation thinned trees are sold as low-grade veneer logs, and achieve prices of the lower end of large saw-logs of 30–40 Australian dollars per m^3). Furthermore, environmental benefits may also be realised; for instance, increased carbon storage in long-term structural products as a result of the value-add products and the shorter plantation rotation [16,17].

3. Experimental study

3.1. General

Twelve half-poles were manufactured around a 115 mm diameter steel mandrel in lengths of 970 mm. The manufacturing concept is detailed in [14] and uses the natural tendency of the veneers to roll about one side, making their gluing into half-shapes achievable around the mandrel, with the veneer grain orientated in the