1. INTRODUCTION

1.1 Overview

Australia produces close to 1 million cubic metres of sawn hardwood timber each year, according to Government statistics, and imports another 142,000 cubic metres, of which more than 90% comes from Indonesia and Malaysia (Caswell, 2005). It is predicted that 9.2 million cubic metres of plantation hardwood pulplogs will be harvested in the latter half of the present decade (Ferguson *et al*., 2002). In New South Wales alone, the consumption of eucalypts as sawn wood was 263,000 m^3 in 2000-01 (ABARE, 2001). Therefore, the less timber that is harvested locally, the more the country will have to rely on imports to meet increasing consumer demand. To reduce the tendency to import sawn timber from overseas, Australian timber drying companies may have to rely on getting most of their timber supplies from hardwood plantations. However, timber companies report a growing difficulty in handling this type of timber for a number of reasons, with the increased amount of variability in timber properties affecting its dried quality being a significant one. Anecdotally, plantation timber appears to be more variable with regards to its properties compared with old growth or regrowth timber. As a result, it is possible that large variability in intrinsic properties may require better control, hence better drying schedules (a series of combinations of dry and wet bulb temperatures applied over a range of moisture contents) that account for such variability may need to be developed.

This section reviews a number of factors involved in considering the variability of the drying and mechanical properties of timber during the optimization of drying schedules to produce high quality timber in the shortest time possible. Firstly, the definition of timber quality according to the Australian/New Zealand Standards (2001) will be stated, followed by the advantages of conventional kiln drying compared with solar drying and air-drying and then the rationale behind *Eucalyptus pilularis* Sm. (blackbutt) as the chosen species for this thesis. Lastly, the contribution of this thesis is described, and an outline of the thesis structure is given.

1.2 Quality in the Timber Industry

There are two issues associated with quality in the timber industry. Quality is not only about minimizing checking or cracking of dried timber (as in the work of Doe *et al.*, 1996; and Langrish *et al.*, 1997), but also about reducing the amount of dispersion of the final moisture contents (Cronin *et al.*, 2003). Kiln drying is often considered to be a better drying practice compared with open—air drying because it allows better control over the final moisture content and involves shorter drying times (Keey *et al.*, 2000). With commercial pressures on them to improve the value of the final dried timber, kiln operators need to lessen the variability of the final moisture content, in addition to minimizing the amount of cracking. In a stack of timber, all boards should be as close to the specified moisture content at the end of the drying process as possible. Therefore, since drying schedules influence the distribution of moisture contents between boards at the end of drying (Cronin *et al.*, 2003), it is important to understand which drying schedules will allow more control over the amount of variation in the final moisture content and hence, control the overall quality within the desired limits.

These desired limits are sometimes stated in timber drying standards. The Australian/New Zealand Standard on the assessment of dried timber quality (AS/NZS 4787:2001) describes the specific requirements expected from various seasoned timber classes with respect to their quality. With regard to the dispersion of final moisture contents, 90% of all moisture contents must lie within the range of 7%—10% if the target moisture content is 8% for Class A timber. Only 0.5% of the maximum proportion of the full dimension of the board is allowed to have surface checking for the same class. In general, furniture and joinery grade products (such as Class A timber) are expected to comply with the criteria set by this standard for target moisture content, moisture content gradients, residual drying stress, checking, collapse, distortion, and discolouration caused by drying. This is in contrast with non—appearance products such as decking and framing that only have to meet the requirements for the target moisture content and distortion.

1.3 Comparisons between Air Drying, Solar Kiln Drying, and Conventional Kiln Drying

Open air drying is placing stacks of timber in a yard and achieving a reduction of timber moisture content using the prevailing wind flowing through the stack (Mills, 1991). Temperature, relative humidity and air passing through the timber stack cannot be controlled with open air drying. Air drying is a relatively slow drying process because of the low drying temperatures compared with kiln drying. Thus, times taken to reach 20-25% moisture content can range from 2-3 months up to 1-2 years (MTC, 2002a), depending on the timber species and size. The rate of air drying is very much dependent on the variations of the local climate. It can vary from close to zero on a calm, damp day to rates fast enough to cause surface checking during dry and windy conditions. In addition, the lack of control over atmospheric conditions with air drying results in a lack of control over the final moisture contents, which is another problem.

Similarly, a major problem when optimizing the design and control of solar kilns is that it is not possible for natural weather conditions to be repeated in consecutive drying runs (Steinmann, 1995). Both air-drying and solar kiln drying are reliant on specific weather conditions during any drying run. On the other hand, conventional kiln drying involves chambers where the temperature, humidity, and air flow through the stack are controlled to give shorter drying times, and drying to a lower moisture content than is feasible with air drying (Plumptre, 1988; Keey *et al*., 2000). It is possible to increase the drying rate, i.e. use higher temperatures, up to a point where a particular timber species can be dried without excessive degrade (MTC, 2002a). At the same time, the control over the relative humidity lessens the steepness of moisture gradients within the timber, hence reducing the development of surface checking.

Despite the fundamental level of control increasing from air drying, to solar-kiln drying, and then to conventional kiln drying, the costs associated with each of these drying processes also increase. The direct costs of conventional kiln drying are much higher than those of air drying and solar-kiln drying. These costs include the capital costs of the equipment, the cost of the fuel, electricity, and supervision (labour) (MTC, 2002a).

However, these costs are partially or fully compensated by the reduction in stock level and faster turnaround of green timber to dried timber.

Therefore, with these features in mind, conventional kiln drying is preferable because of the ability to control the drying conditions, to achieve timber moisture contents suitable for specific end-uses (MTC, 2002a), and to potentially produce better timber quality in the presence of variability in timber properties.

1.4 Blackbutt Timber (*Eucalyptus Pilularis* Sm)

The tree species chosen for this study was blackbutt (*E.pilularis*), because blackbutt is the predominant planted hardwood species in NSW, Australia (Boland *et al*., 1989). It is most abundant in many coastal areas between south of Bega up to southeastern Queensland. In addition, “old growth” blackbutt is highly favoured by sawmillers since it produces good timber for general purpose. As a result, it is considered to be one of the most important eucalypts for planting in NSW and Forests NSW anticipates to establish a total blackbutt estate of some 40,000 hectares by the year 2010 (Johnson and Nikles, 1996).

There are a number of reasons why blackbutt is a preferred species in NSW hardwood plantations (Johnson and Nikles, 1996). These reasons include the point that the growth and survival of blackbutt in routine plantations over a wide range of ex-forested sites is proven; there is superior growth and reasonably high survival rate compared with most other species; and lastly, the wood is marketable.

1.5 Thesis Contribution

The main contributions of this thesis are as follows:

1) Measure the fundamental, transport and mechanical properties of both regrowth and plantation blackbutt timber and, hence, quantify the degree of normality of each parameter’s distribution;

2) Determine how, why and to what extent the properties of plantation blackbutt timber are more variable than the properties of regrowth blackbutt timber, for within a single tree and between trees from the same location and between different locations;

3) Determine if any correlations exist between the fundamental, transport and mechanical properties of both regrowth and plantation blackbutt timber, and how strongly they are correlated. In addition, if any correlations exist between the parameters, it may be worthwhile to estimate the diffusion coefficient by using the parameters that are easy to measure, such as the basic density or the initial moisture content, through using empirical equations. Such information may be used to determine timber drying schedules suitable for other species of regrowth and plantation blackbutt timber.

4) Evaluate the effects of different drying schedules for both regrowth and plantation blackbutt timber that account for the measured variabilities. The reasons for the effects will be investigated.

1.6 Thesis Structure

- Chapter 1: This chapter presents the problem statement for the project, the issue of quality in the timber drying industry, comparisons made between conventional kiln drying, air—drying and solar drying, reasons regarding why blackbutt timber has been the species chosen for this thesis project, contributions the thesis will make to the field of timber drying, and lastly, the thesis outline.

- Chapter 2: This chapter presents an overview of previous work on the development and evaluation of different drying schedules. This chapter includes literature reviews on work to optimize kiln drying schedules to minimize the dispersion of final moisture contents, optimizing kiln drying schedules to minimize checking or cracking in dried timber, optimizing drying schedules based on the biological variability of timber properties, and what has been found so far on variability in hardwood timber properties and the effects on timber quality within trees and between trees.

- Chapter 3: This chapter describes the materials, methods, and fitting procedure used to measure the fundamental, transport and mechanical properties of both regrowth and plantation blackbutt timber. These measurements were required to determine if correlations exist between the parameters, and if so, use such information to evaluate different drying schedules. These properties include the initial moisture content, the basic density, the diffusion coefficient, the failure stress, the failure strain, the modulus of elasticity, and shrinkage.

- Chapter 4: The fourth chapter presents the measured fundamental and transport properties of both regrowth and plantation blackbutt timber. This chapter also reports the identified trends of these properties that exist within a tree, and the analysis of variance to determine which effects were significant sources of variation. Investigation of a suitable sample size for the analysis of variance was also conducted to represent the population statistics.

- Chapter 5: This chapter presents the measured mechanical properties of both regrowth and plantation blackbutt timber. This chapter also reports the identified trends of these properties that exist within a tree, and the analysis of variance to determine which effects were significant sources of variation. A suitable sample size for the analysis of variance was also investigated to represent the population statistics. In addition, the extents of normality for the fundamental, transport, and mechanical properties were assessed in this chapter. Significance tests were also applied to show if the results of regrowth and plantation blackbutt timber were significantly different from each other.

- Chapter 6: This chapter reports the results of the Principal Components Analysis applied to the measured timber properties. Empirical correlations using the initial moisture content and the basic density were analysed for their suitability when estimates of the diffusion coefficient are needed prior to drying. This chapter also focuses on the development of optimized drying schedules for regrowth and plantation blackbutt timber. The optimization procedure used was based on the method developed by Pordage (2006), and the measured variability timber properties presented in the fourth and fifth chapters. Lastly, the results of the optimized drying schedules for regrowth and plantation blackbutt timber were compared based on the total drying time.

- Chapter 7: This final chapter summarises the conclusions drawn from this project and presents further recommendations for future studies arising from this work.