MICROWAVE ASSISTED DRYING OF RADIATA PINE VENEER

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ABSTRACT

The potential role of microwave technology in veneer drying is 2-fold

1. As an addition to traditional conveyor belt convection / jet drying to accelerate the drying process and improve the quality attributes of the dried veneer.
2. As an addition to secondary veneer drying processes for moisture levelling and stress reduction.

The main advantages of incorporating microwave technology for drying veneer arise in

- Speeding up the rate of drying
- Reducing within and between veneer moisture content variability
- Moisture levelling of wet pockets
- Eliminating drying defects
- Improving the quality attributes of dried veneer

Keywords: Microwave processing, veneer drying, bio-composites, plywood, LVL manufacture, radiata pine, veneer quality.

INTRODUCTION

Microwave technology can be used to accelerate 4 stages of veneer / plywood manufacturing (Vinden *et al.* 2007):

- Rapid heat conditioning / softening of veneer logs prior to peeling / slicing.
- Rapid drying and /or moisture levelling of veneer prior to gluing
- Continuous rapid curing of resin during on-line pressing
- Conditioning (improving the permeability) of waste peeler cores for preservative treatment.

The heating of veneer logs using microwave technology has potential advantages over steaming or hot water conditioning. These include:

- Very fast heating of logs that could potentially be provided in-line, and just-in-time to coincide with peeling or slicing operations)
- Low environmental impact (water pollution) and the use of clean technology
- Energy efficiency through the direct placing of microwave energy anywhere within the cross-section of the log.

Rapid drying or moisture levelling of veneer (the subject of this paper) can potentially use microwave technology to speed up the drying process (Torgovnikov and Goryaev 1995) and improve the quality attributes of the dried veneer (moisture uniformity within and between veneer sheets, veneer flatness, edge straightness, veneer squareness, shrinkage properties and other quality attributes).

Microwave curing of resin is now used commercially for the continuous in-line lamination of veneer lumber (LVL). It has advantages of low energy use, quality adhesion and speed.

Waste peeler cores pose a problem in terms of value adding, especially given the refractory nature of core (heartwood) material of most wood species. However, microwave conditioning can be used successfully to improve wood permeability and facilitates complete preservative penetration of the core cross-section (Sugiyanto *et al.* 2009).

Energy use during the drying of veneer is the most critical process in veneer production, affecting production costs and the quality of the finished product. Variation in final moisture content is a critical issue affecting a wide range of quality variables in the end product. Attempts to remedy this variability include the use of veneer sheet segregation based on veneer moisture content or the imposition of post drying conditioning. The variables impacting on jet drying have been summarised by Comstock (1971). Relatively little work has been undertaken however to evaluate the potential of microwave drying of veneer, primarily because of a perception that energy costs may be too high.

Moisture content variation and redrying

The main objective in veneer drying is to reduce veneer moisture to a level (5-10%) where optimum bonding is achieved (Baldwin 1981). The maximum moisture content should not exceed 14-18% to avoid potential mould and sap-stain development. Final moisture contents of 10% or less are recommended by Perry (1948), since this equates to the equilibrium moisture content for plywood in use.

A key quality issue relates to the variation in final moisture content. Redrying of veneer may affect between 10-15% of total veneer drying output (Walker 1993). This inevitably results in (Kollman *et al.* 1975):

- Low veneer quality (warping due to veneer buckling)
- Staining from wet pockets
- Poor uniformity in veneer moisture content
- Additional labour costs associated with stacking and de-stacking veneers

Redrying inevitably leads to:

- A reduction in output
- Increases in manufacturing costs
- Unnecessary veneer shrinkage
- Veneer embrittlement
- Down stream gluing problems

Over-drying of veneer and its impact on poor adhesion has been reviewed by Resch *et al.* (1970). They identified the likely causes of poor bonding to include:

- A decrease in hydroxyl bonding potential
- Physical damage to surface fibres
- Surface inactivation due to extractives

Many veneer-drying operations have attempted to reduce moisture content variation by:

- Drying to lower average moisture contents (3-5%)
- Introducing jet air dryers
- Segregation of predominantly sapwood or heartwood veneer sheets based on in-line automated determination of sheet moisture content.

All of these methods have had some success. However, redrying operations are still a requirement in most mills.

Redrying often involves recycling of the veneer through the main veneer drying system leading to the over-drying problems described above. However, the use of secondary drying has been recommended by Resch *et al.* (1970) in that it would facilitate freeing up of the main drying system and the use of higher feed speeds for drying the bulk of veneer. In addition microwave technology has been considered as potentially advantageous given:

- The small area or footprint occupied by the equipment
- The attributes of microwaves that result in their preferential attraction to wet pockets or wetter veneer, thus potentially evening out moisture gradients
- The relatively low energy costs associated with heating materials characterised with low moisture contents
- The ability to direct microwave heating into the material and the subsequent positive pressure developed from within the material to aid mass vapour flow to the surface rather than relying on heat conduction from the surface and then a slow process of moisture diffusion to the surfaces of the veneer
- The ability to direct different levels of microwave energy to specific areas in the veneer or wood where it is needed to aid or accelerate drying where the material is refractory and reduce moisture variability

Thus the role of microwave technology in veneer drying is potentially 2-fold:

1. Incorporation of microwave technology into the traditional conveyor belt convection / Jet drying to accelerate the drying process.
2. As an addition to a secondary veneer drying process for moisture levelling and stress reduction.

Rate of veneer drying

Studies into the drying of Sweetgum veneer by Olson and Arganbright (1983) highlighted that equivalent drying times could be achieved by drying at 93°C with 15kW microwave power, 149°C at 5kW or 240°C without microwave assistance. They also concluded that drying uniformity was very poor if veneer was dried with impinging hot air alone; that the best drying uniformity was obtained using impinging hot air and 2.5kW microwave power, but that above 2.5kW, drying uniformity decreases.

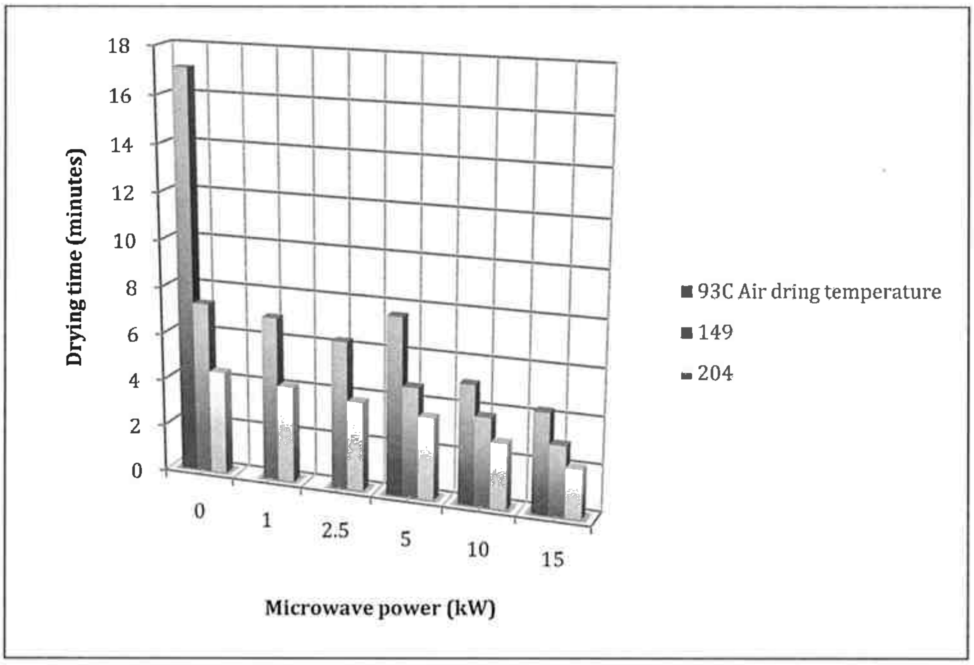

Figure 1. Drying time for Sweetgum veneer as a function of drying temperature and MW power (adapted from Olson & Arganbright, 1983).

The effects of drying temperature (with and without microwave power) have been investigated by Chen *et al.* (1990) for single and double veneer sheets. Their results are summarised in Figure 2 and illustrate a substantial acceleration in drying resulting from the additional use of microwave drying.

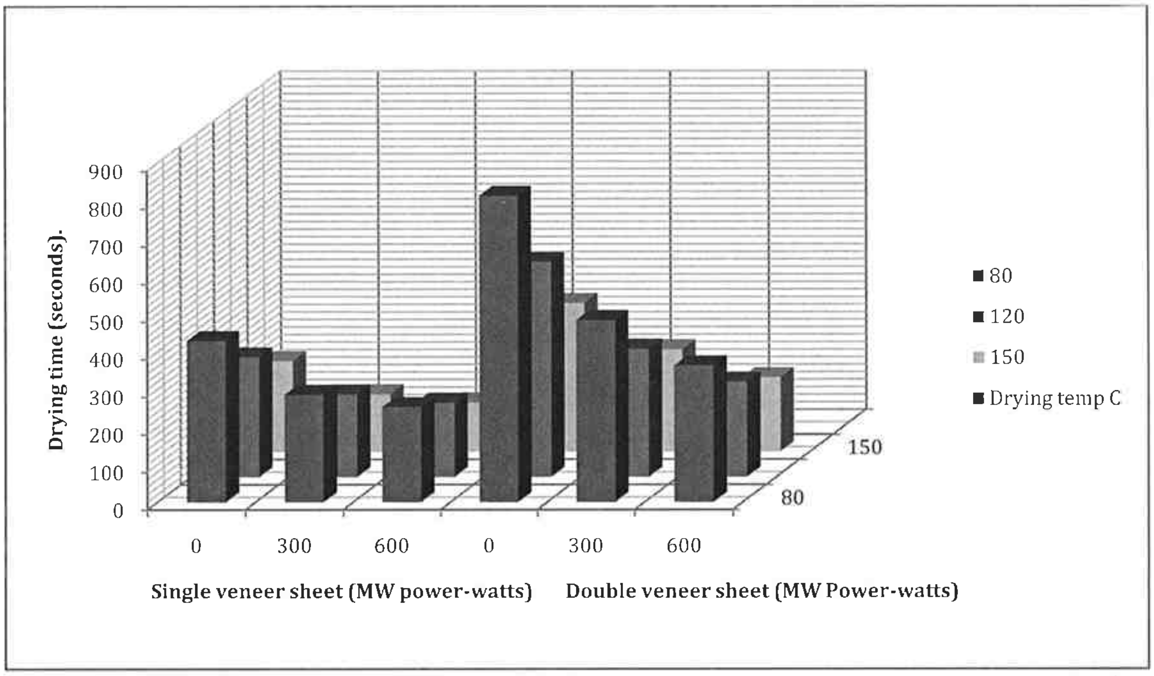

Figure 2. Drying time as a function of drying temperature and microwave power (single and double sheets of veneer). Adapted from Chen et al. (1990)

Objectives

The application of microwave technology to effect faster rates of veneer drying is a relatively simple technical operation and could be implemented as a simple add-on to traditional drying practices. However, research to optimise the application of microwave technology and to unravel the impact of the wide range of interacting variables influencing the quality output of the drying process is complex. Most microwave research uses conveyor belt application of the product through a microwave field. Ultimately the challenge is to define and prove an online system of microwave application. During peeling operations, however, the basic density and moisture content of the peeled veneer, grain deviation about knots, presence of compression wood and heartwood formation can vary enormously. Whilst process control technology can now measure raw material attributes and vary the intensity of applied microwaves to potentially optimise drying operations, the evaluation of the impact of raw material variables in a dynamic microwave plant is problematical. In this preliminary investigation the objective is to develop a standardised system of microwave application to static veneer samples so that the effects of raw material attributes and interacting processing parameters can be modelled under carefully controlled conditions.

The objectives of this investigation are:

1) To evaluate the suitability of a laboratory bench top microwave to determine the acceleration in drying of radiata pine veneer through microwave versus oven drying and the potential impact for microwave technology to accelerate veneer drying and reduce moisture content variability in the final product.

2) To examine the impact of microwave drying on the quality of the dried veneer.

MATERIALS AND METHOD

Sample preparation and drying

Green radiata pine veneer measuring 1.5 and 3.0 mm in thickness was selected green off the peeler at the Carter Holt Harvey LVL Plywood Mill at Myrtleford, Victoria Australia. The sheets were block-stacked and stored in polythene bags and maintained at 4°C for 1.5 months prior to use. The veneer samples were each cut into sheets measuring 200 mm long x 100 mm wide.

Microwave drying experiments were conducted using a 6kW microwave generator (frequency = 2.45GHz). A wave-guide chamber measuring 1000 mm in length, 248 mm in width and 124 mm in height was connected as illustrated in Figure 3. A rotating sample holder (7 mm in thickness and 18 mm in diameter) was constructed to provide rotation of samples at 0.05 cm/sec. Hot air circulation (120°C) at a speed of 0.05 revolutions/sec. was also provided. Two veneer samples were orientated vertically on the edge of the sample holder where microwave energy was at a maximum. Veneer moisture content was determined every 50 seconds by weighing until samples had achieved a final moisture content of between 10-15% mc.

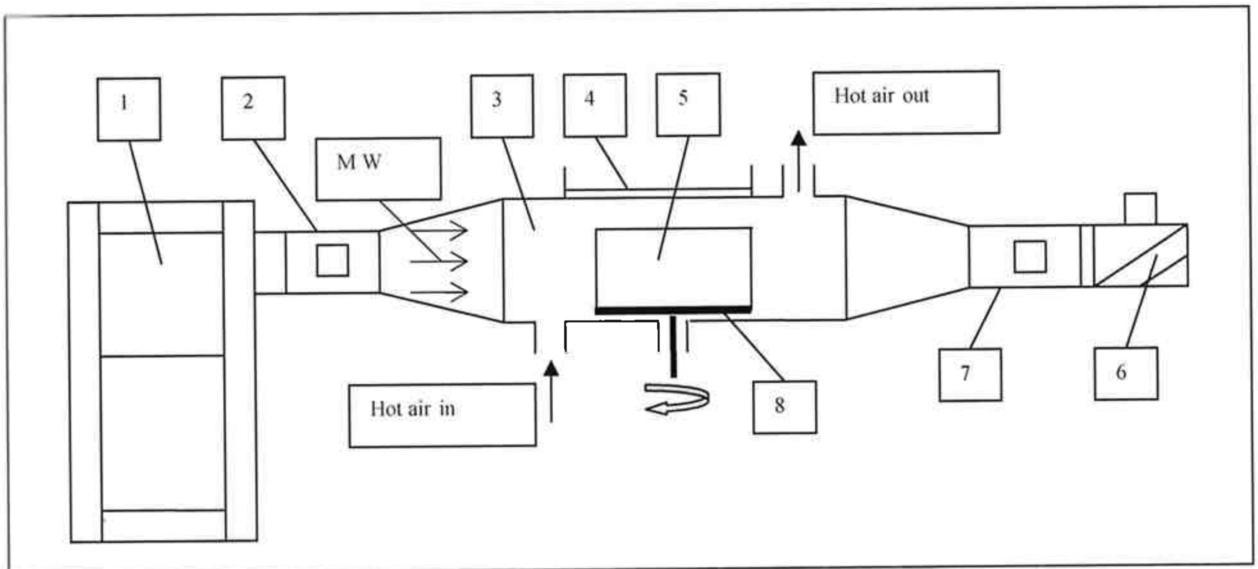

Figure 3. Diagram of the microwave experimental installation.
1 – Microwave generator (frequency - 2.45GHz, microwave power 6kW), 2 - sensor for measuring generated and reflected microwave power, 3 – microwave chamber, 4 – chamber cover, 5 - veneer sample, 6 – water load, 7 - sensor for measuring transmitted microwave power, 8 – rotating platform for samples.

Conventional drying was achieved using an experimental oven set at 105°C. Veneer samples were weighed every 5 minutes to determine moisture content. Drying was terminated once samples had achieved veneer moisture contents of between 10-15% mc.

Veneer moisture content profiles were determined by cutting veneer sheets into outer, inner and middle sections as illustrated in Figure 4 and drying at 105°C to constant weight. The average moisture content was determined from weighing the moisture contents of individual veneers.

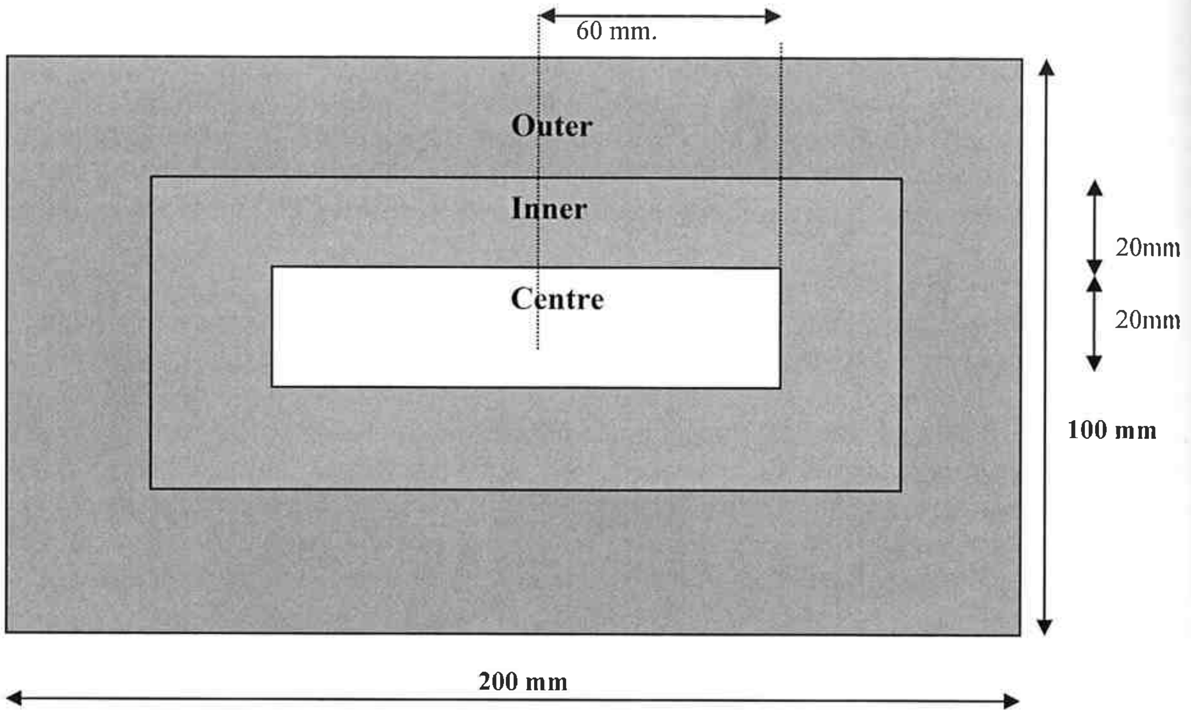

Figure. 4. Cutting pattern of veneer samples to determine moisture content profiles.

The amount of energy absorbed by veneer was calculated using Equation 1, used by Troughton and Clarke (1987).

$$AE = Mw \times Cpw \times \Delta t + m_{H20} \times CP_{H20} \times \Delta t + \Delta m_{w.ev} \times L \qquad \text{......(Eq 1).}$$

Where:

AE = absorbed energy
Mw = wood mass (kg)
Cpw = heat capacity of wood (kJ/kg°C)
Δt = temperature change (°C).
m_{H20} = water mass (kg)
CP_{H20} = heat capacity of water (4.19 kJ/kg/°K)
L = latent heat (2400kJ/kg)
$\Delta m_{w.ev}$ = evaporated water mass (kg)

Assumptions: All energy is absorbed either by the veneer or water load and energy losses are negligible and can be neglected; water evaporates at 100°C.

Microwave energy consumption is the amount of energy absorbed (AE) by the wood veneer (kJ) and the amount of energy needed to evaporate wood water (kJ).

Energy absorption is the percentage of microwave energy absorbed by the veneer relative to the total amount of energy released by the microwave / magnetron (= microwave power (W) × time of exposure (sec)).

Veneer quality attributes measured after drying

Veneer twist, squareness, edge straightness and waviness or flatness and volumetric shrinkage were measured after drying using Australian Standard AS 2098.4. Residual drying stresses in the transverse and longitudinal directions of the veneer sheet were determined using the methodology described by Smith *et al.* (1994).

RESULTS

The moisture content profiles for veneer sections illustrated in Figure 4, together with veneer moisture contents (estimated from the green weight /unit area of veneer) following microwave drying and kiln drying are summarised in Table 1 for 3.0 and 1.5 mm radiata pine veneer. An analysis of variance for veneer moisture profiles indicated no significant differences between the two drying methods, three moisture profiles or veneer thickness. Green weight per unit area (g/cm^2) provided an accurate indication of moisture content irrespective of veneer thickness or drying method. Microwave irradiation provided much faster drying (×2.9 for 3 mm veneer and ×5.0 for 1.5 mm veneer) compared to kiln drying.

Table 1. Mean moisture content profile and drying time for 3 and 1.5 mm radiata pine veneer dried by microwave and conventional drying to 10-15% MC.

Drying methods	Veneer thickness, mm	Moisture profile, (%)				Moisture content, (%)		Drying time, (Minutes)
		Outer	Inner	Centre	Average	Estimated	Initial	
Microwave drying	3	13	12	13	13	15	128	8.0
Conventional drying	3	12	15	16	14	14	59	23
Microwave drying	1.5	14	13	14	14	15	66	3.4
Conventional drying	1.5	12	14	14	13	11	79	17

Microwave energy consumption, energy released and energy absorption are calculated in Table 2. The 3 mm veneer consumed 5 times more microwave energy (88kJ) than the 1.5 mm veneer (18kJ). The microwave supplied approximately 2.5 times more energy (447kJ) to evaporate and remove moisture from the 3mm veneer samples compared to 181 kJ for the 1.5 mm veneer. The energy absorption achieved in drying the 3mm veneer was twice that of the 1.5mm veneer (20% rather than 10%) reflecting the substantially higher initial moisture content of the 3 mm veneer (128% mc compared to 66% mc) and longer drying times (8 minutes compared to 3.4 minutes).

Table 2. Microwave energy consumption, energy release and energy efficiency for 3 and 1.5 mm veneer.

Veneer samples	Initial moisture content, (%)	Energy (kJ)		Energy absorption, (%)	Drying time (minutes)
		Consumed (input)	Released (output)		
3 mm veneer	128	88	447	20	8.0
1.5 mm veneer	66	18	181	10	3.4

The rate of drying of 3mm veneer using microwave was approximately 7 times that of conventional drying and 4 times faster for the 1.5 mm veneer. The difference is attributable to a faster rate of drying for thinner veneer during conventional drying (3.8% / minute for 3 mm compared to 2% / minute) whereas there was only a slight acceleration in drying for thinner veneer using microwave drying (15.5% / minute compared to 14% / minute).

Veneer quality attributes measured after drying including veneer twist, squareness, edge straightness and waviness or flatness and volumetric shrinkage and residual drying stresses were improved following microwave processing compared to oven drying and will be reported in part 2 of this paper.

DISCUSSION AND CONCLUSIONS

Microwave drying was characterised with a high final moisture profile uniformity (the same mean moisture contents for outer and centre sections for both the 3 mm and 1.5 mm veneer). The laboratory microwave apparatus design proved to be successful and can be used to generate valuable data that can be used in the design of a commercial microwave assisted drying plant. However, more work is needed to generate data to characterise the influence of raw materials on drying rate.

The percentage absorption of microwave is a measure of microwave absorption under experimental conditions rather than microwave absorption efficiency. In a commercial plant it can be anticipated that all microwave energy will be absorbed by the veneer. The rate of drying of 3 mm veneer is approximately 7 times higher (14% mc/min) for microwave assisted drying compared to oven drying (2% mc/min). The rate of drying of 1.5 mm veneer is 15.5% mc/min compared to 3.8% mc/min for oven drying, 4 times faster. Thus in terms of veneer thickness the thinner veneer (1.5 mm) dries 1.1 times faster than the 3 mm veneer.

The main advantages of incorporating microwave technology into existing veneer drying operations arise in:

- Speeding up the rate of drying
- Reducing within and between veneer moisture content variability
- Moisture levelling of wet pockets
- Eliminating over drying defects
- Improving the quality attributes of dried veneer.

Part 2 of this paper will focus on the quality benefits arising from incorporating microwave drying.

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