Moisture Profile of Two Veneer Thickness Following Microwave Heat Gun Drying

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Abstract

Application of microwave technology on the wood industries, mainly wood drying begun shortly after World War II. Full application of microwave technology at production line of wood drying industries is still being adopted in limited scales. This is due to insufficient knowledge or lack of understanding of how microwave dries wood, it consumes huge of electricity, and needs an intensive capital investment. However, several researchers have begun to conclude that employing microwave technology on wood drying will provide faster drying time, higher in rate of drying and uniformity in moisture content profiles of dried wood and no air pollution. This research is designed to investigate the application of microwave technology for drying of wood veneer in comparison to conventional drying. Drying attributes consist of moisture profiles of dried veneer, drying time, rate of drying and microwave energy consumption, using two veneer thickness of Radiata pine. The results indicated that microwave technology provides faster drying and results in higher moisture profiles of dies veneer and rate of drying compared to conventional drying.

Key words: moisture profiles, microwave drying, two-veneer thickness, conventional drying.

Introduction

The lack of understanding of the mechanisms of wood veneer drying and the behavior of veneer during drying has resulted in poor glue-ability and performance of the final glued veneer products. Problems arising during veneer drying range from uneven moisture distribution and drying defects, to over drying. However, the most common operational difficulty in veneer drying is the time required for drying, which ranges from minutes to hours using conventional drying to seconds or minutes using microwave or radio frequency drying.

Microwave drying has been investigated as an option for drying wood and veneer since the late sixties (Barnes *et al*. 1976). However, the applications of this technology on a commercial scale for veneer wood drying have been slow to take off. Many studies have been carried out to improve our understanding of the factors influencing veneer drying, such as the influence of wood species, density and initial moisture. Microwave variables, for example microwave design, power, and times of exposure/speed, have been included in these studies (James and Hamill 1965, Resch *et al.* 1970, Olson and Arganbright 1983, Peyskens *et al.* 1984, Martin *et al.* 1987, Chen *et al.* 1990, Torgonikov and Goriev 1995).

Microwave drying differs from conventional drying in the way that microwave energy causes excitation and friction (dissociation) of water molecules or water, which manifests itself as heat. Microwave energy is a high frequency electronic energy compared to Radio Frequency (RF). It is superior in penetration; it enhances the rate of moisture evaporation and optimizes the overall drying process (Metaxas and Meredith 1983). The higher the moisture content of material (wood) the higher the microwave energy absorbed by wood. Metaxas and Meredith (1983) also pointed out that the rise in volumetric heat of wood results in the boiling of wood moisture. The internal gas pressure also drives the wood moisture from interior layers to the surfaces of the wood. In contrast to microwave drying, conventional drying relies on heat conduction from the outer surface wood layers towards to the inner layers. Therefore, the thicker the wood at cross-section the slower the rate of evaporation (Metaxas and Meredith 1983). The effect of various initial moisture contents, veneer thickness and microwave power on moisture leveling on the quality of microwave veneer drying has received scant attention in the literature.

The aims of the studies outlined in this research are to:

- examine the factors affecting the quality of veneer obtained during drying;
- compare the veneer moisture profiles through the samples resulting from microwave drying in comparison to the conventional drying; and
- determine the rates of drying of veneer using two drying methods.

Materials and Methods

The sources of Radiata pine (*Pinus radiata*) veneer used in this experiment were obtained from Colt Hatley Melbourne. The sample dimensions were 200 mm long, 100 mm wide and 3 mm (veneer *A*) and 1.5 mm (veneer *B*) in thickness. Ten replicates were used to determine the veneer moisture level for each drying method and veneer thickness.

Microwave Drying

A modified 900 kW SHARP microwave oven was used for these experiments. The microwave oven was connected to a wave-guide (1000 x 250 x 120 mm in length, width and height, respectively). A sample holder was constructed which rotated samples at 0.05 cm/sec. The sample holder was 0.7 cm in thickness and 10 cm in diameter (Figure 1). In addition hot air circulation (120ºC) was provided at a speed of 0.45 m/sec. Two veneer samples were placed vertically on the edge of the sample holder, where the distribution of microwave energy was maximum. The veneer was weighed and re-weighed every fifty seconds until the veneer moisture content (MC) was within the range of 10~15%.

Conventional Drying

The oven temperature (approximation to conventional kiln drying) was set up at 105ºC to dry veneer for conventional drying. MC was determined by weighing and re-weighing every five minutes until the veneer moisture content was within the range of 10~15%.

Moisture Content Profile

Veneer moisture profile was determined by cutting the samples into 3 sections across and along the grain direction. These sections were labeled as the outer, inner and center, respectively. The center was then cut into two sections, 6 cm long and 2 cm wide. Each sample was weighed before and after oven drying. The veneer moisture profile was then constructed from the average of moisture content of individual veneer samples. Correction factors were applied to ensure weighting of larger samples. The cutting pattern of veneer samples is illustrated in Figure 2.

Veneer Drying

Veneers were placed perpendicular to the microwave wave-guide on the sample holder and rotated by an electric motor. Speed of rotation and microwave power were set out in conjunction with the experimental design variables. The weights of veneer before, during and after microwave drying were recorded. A stopwatch (± 0.01 sec) and an electronic balance with an accuracy of ± 0.01 g were used. Micro calipers with an accuracy of 0.01 mm were also used to measure the veneer dimensions. This experiment was conducted at the Microwave Laboratory, School of Forestry, The University of Melbourne, Creswick. A diagram of the microwave plant is shown in Figure 1.

A description of how the microwave works and dries wood is summarized as follows:

1) The magnetron changes electrical energy into microwave energy.
2) The magnetron has an output power ranging from 425 to 900 W, which can be adjusted at the control panel. A signal lamp indicates that the magnetron is ready to be used and operated.
3) A portable microwave detector is used to detect any energy leakage to ensure safety of the operation.
4) The water load is used for catching excessive waves, which are dissipated through the water loaded.
5) A 5HP motor dynamo is operated to rotate the sample holder where veneer is placed.
6) A heat gun provided heated air at a speed of 70 m/min at 300ºC. This accelerates the expulsion of vapor out of the microwave cavity to avoid moisture condensation and maximize the microwave energy absorption by the wood veneer.

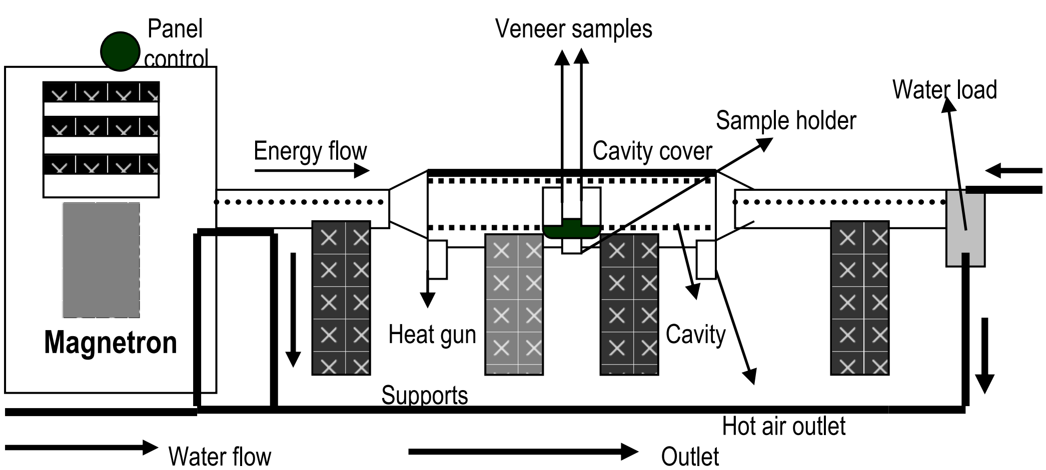

Figure 1. A schematic diagram of the microwave plant to dry wood at the School of Forestry, The University of Melbourne, Creswick.

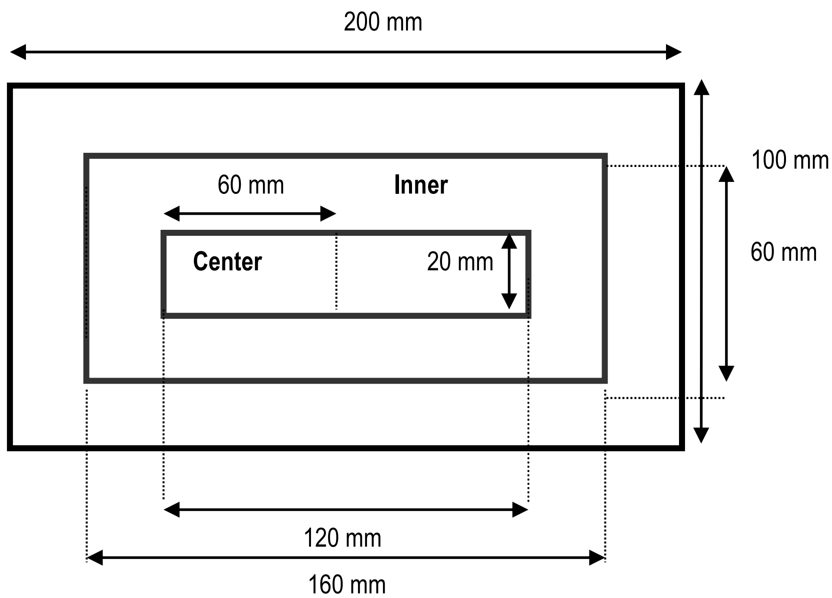

Figure 2. The cutting pattern of samples to determine veneer moisture content profiles.

Microwave Energy Consumption (MEC)

Microwave energy consumption (MEC) is the amount of energy absorbed by the wood veneer (kJ) and the amount of energy needed to evaporate wood water (kJ) during drying. Energy efficiency (EF) is the percentage of microwave energy absorbed by wood veneer (output) to the total amount energy released by microwave/magnetron (input), which can be computed by multiplying microwave power (W) with time of exposure (sec). Subarudi (1996) used the following equation, developed by Troughton and Clarke (1987), to determine the amount of energy absorbed by wood veneer. Troughton and Clarke (1987) used this equation to measure the moisture content of unseasoned veneer and lumber by governing the relationship between moisture content and the surface temperature, as described with equation outlined below.

$$\mathbf{AE = Mw \times Cpw \times \Delta t + m_{H20} \times CP_{H20} \times \Delta t + \Delta m_{w.ev} \times L}$$

where:

AE = absorbed energy
Mw = wood mass (kg)
Cpw = heat capacity of wood (cal/gºC)
Δt = temperature change (ºC),
m_{H20} = water mass (kg)
CP_{H20} = heat capacity of water (4.19 kJ/kg/ºK)
$m_{w.ev}$ = mass of water evaporated (kg)
L = latent heat (2400 kJ/kg)

Assumption:

(i) energy losses are negligible neglected. i.e. all energy is absorbed by wood and water.
(ii) water evaporates at 100ºC.

Results

Veneer Moisture Profile

Average veneer moisture content (MC) profiles, the veneer MCs (estimated from the green weight per area of veneer), and drying time for the two veneer thickness, i.e. 3 mm and 1.5 mm in thickness, respectively, dried by two drying methods (microwave and conventional) are summarized in Tables 1 and 2.

Table 1 indicates that the highest mean MC profile (13%) from veneer *A* (dried by microwave) is recorded from the outer or center section, while for conventional drying the highest mean of moisture content profile (16%) occurs in the center section. This highest coefficient of variation also arises for conventional drying in the center section (53%) and in the microwave samples from the outer section (50%). Interestingly, both drying methods had similar standard deviations (5%). Both drying techniques resulted in similar average final moisture content, 13% and 14% for microwave and conventional drying respectively, as illustrated in Figure 3.

Table 2 indicates that veneer *B* dried by microwave had an average moisture content profile of 14%. This is similar to that recorded for conventionally dried veneer (13%). Both drying methods had a similar average minimum moisture content profile (8%).

Table 1. Mean moisture content profile and drying time for veneers *A* (3 mm in thickness) dried by microwave and conventional drying to 10~15% MC.

Drying methods	Moisture Profile (%)				Moisture Content (%)		Time of drying (min)
	Outer	Inner	Center	Avg**	Estimated (*)	Initial	
Microwave*(MW)	13	12	13	13	15	128	8.0
Conventional*(CD)	12	15	16	14	14	59	23.0
Max. MW	25	21	17	21	17	137	9.3
CD	15	29	36	24	16	104	41.0
Min. MW	5	8	5	6	11	98	6.6
CD	9	8	8	9	10	44	15.0
St.dev. MW	7	5	4	5	2	11	1.0
CD	2	6	8	5	2	19	9.0
CV. MW (%)	50	37	33	39	14	9	13.0
CD (%)	18	42	53	37	32	32	40.0

*mean of ten replication, st.dev = standard deviation, CV =coefficient of variation
** average, (*) estimated from green weight per surface veneer area

Table 2. Means for moisture content profiles and drying times for veneers *B* (1.5 mm in thickness) dried by microwave and conventional drying.

Drying methods	Moisture Profile (%)				Moisture Content (%)		Time of drying (min)
	Outer	Inner	Center	Avg**	Estimated (*)	Initial	
Microwave* (MW)	14	13	14	14	15	66	3.4
Conventional* (CD)	12	14	14	13	11	79	17.0
Max. MW	19	17	22	18	16	125	5.3
CD	24	18	24	17	13	122	28.0
Min. MW	8	8	7	8	12	33	1.7
CD	8	8	7	8	6	42	10.0
St.dev. MW	4	3	5	3	7	31	1.2
CD	5	4	6	4	2	35	7.0
CV. M W (%)	27	26	34	23	11	46	35.0
CD (%)	44	27	42	30	21	45	41.0

*mean of ten replication, st.dev = standard deviation, CV =coefficient of variation
** average, (*) estimated from green weight per surface veneer area

In contrast to the 3 mm veneer, the highest coefficient of variation of moisture profile for veneer *B* (dried by microwave) was recorded in the center section (34%), whereas the conventionally dried veneers had the highest coefficient of variation in the outer section (44%). This is illustrated in Table 2 and clearly indicates outer both drying methods have different patterns of drying.

Green Moisture Content (GMC)

Table 1 indicates that veneer *A* has higher average green moisture content (GMC), 128% and 59% for the microwave and conventionally dried samples respectively, than those recorded for veneer *B*, which had an average of GMC 66% and 79% for microwave and conventional samples. However, veneer *A* was more uniform in GMC than veneer *B*. This is probably related to the technological attributes both veneer thickness such as the proportion of earlywood and latewood and wood knots on veneer *A*.

Drying Time

Microwave drying clearly provides faster drying times. Veneer *A* was dried 2.9 times faster using microwave compared to conventional drying (Table 1) and veneer *B*, 5 times faster drying (Table 2). Table 1 also highlights that microwave drying resulted in greater drying time uniformity (CV = 13%) for veneer *A* compared to 40% for conventional drying. A comparison of the drying times recorded for the two drying methods is illustrated in Figure 4. This figure illustrates that the drying time for the 3 mm veneer (*A*) with microwave is 2.4 times slower than for 1.5 mm veneer, whereas using conventional drying the rate of drying for the thicker veneer was 1.5 times slower. Table 2 also indicates that the initial moisture content of veneer is an important determinant of microwave energy consumption, energy released and energy efficiency. It is thought that the lower coefficient of variation in GMC for veneer *A* reduces the coefficients of variation of other variables, such as energy consumed, energy released and energy efficiency and drying time. All of the variables recorded for veneer *A* were much lower than those for veneer *B*.

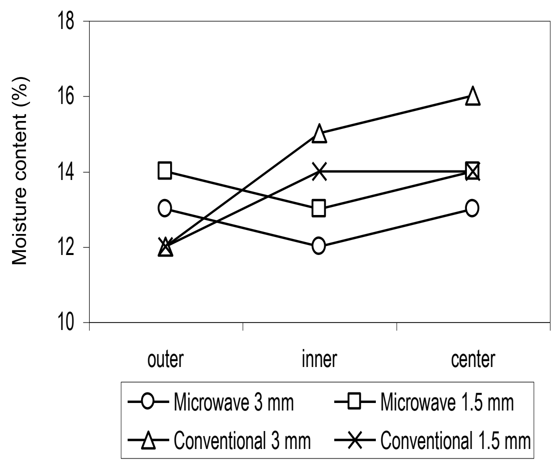

Figure 3. The average of moisture profile of two veneer samples dried by microwave and conventional drying.

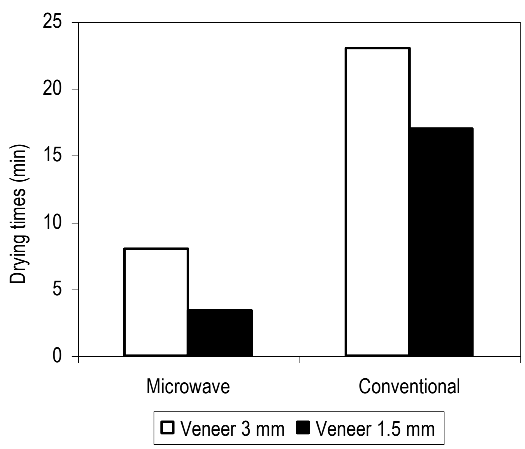

Figure 4. The drying times of two veneer samples dried by microwave and conventional drying.

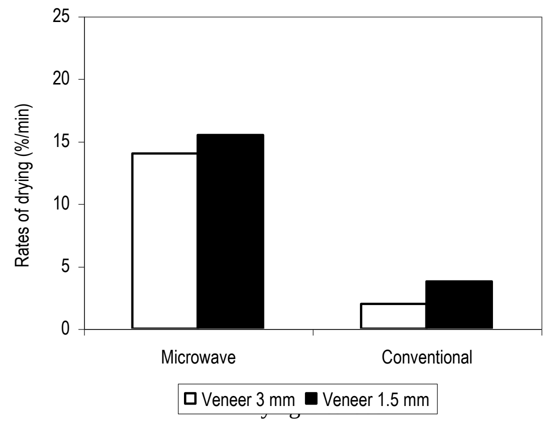

Figure 5. Drying rates of two veneer samples dried by microwave and conventional drying.

Rate of Veneer Drying

The rates of drying of two veneer *A* and *B* dried by microwave and conventional drying are summarized in Table 5.

Table 5. The rates of drying of two veneer samples using microwave and conventional drying.

Samples	Rate of drying (%/minutes)	
	Microwave	Conventional
Veneer *A**	14.0	2.0
Max	16.5	2.3
Min	11.6	1.6
St.dev	2.0	0.3
CV (%)	13.0	15.0
Veneer *B**	15.5	3.8
Max	23.0	5.5
Min	12.0	1.3
St.dev.	4.0	1.1
CV (%)	26.0	29.0

Notes: Veneer *A* and *B* are 3 and 1.5 mm in thickness, respectively
*average from 10 replicates

Table 5 indicates that the rate of drying of the two veneer *A* and *B*, dried by microwave is faster than for conventional drying. The rate of drying of veneer *A* dried by microwave is 7 times higher (14%/minute) than that recorded for conventional drying (2%/minute). In contrast to veneer *A*, veneer *B* dried at an average rate of (15.5%/minute) during microwave conditioning, 4 times higher than conventional drying (3.8%/minute).

In terms of veneer thickness, the drying rate of veneer *B* dried by microwave is 1.1 times higher than that recorded from the veneer *A*, while the veneer *B* dried by conventional drying had a drying rate 2 times higher than that of the veneer *A*. It appeared that veneer thickness did not influence the rate drying during microwave drying, whereas the impact of veneer thickness on drying rate for conventional drying is very significant.

Discussion and Conclusion

Discussion

Two veneers *A* and *B* dried by microwave and conventional drying have different moisture profiles within and between the veneer sections. Moisture uniformity between the outer, inner, and center sections of veneer *A* and *B* was higher for microwave drying than for conventional drying. The lowest moisture profiles for both veneer thickness *A* and B under conventional drying was recorded in the outer sections.

The different patterns (Figure .3) of MC profiles (MC of outer, inner, and center sections) between the two veneer sample types dried by microwave and conventional drying was probably due to fundamental different ways as described earlier. Conventional drying results in the movement of moisture from outer surface of veneer from outside inward, whilst microwave tends to heat up moisture preferentially on the inside. Thus conventional drying reflects a process involving external heating system and temperature transmission by convection from the outside of the product (Barnes *et al.*, 1976). The heat is conducted from the outer layer of fibers towards the interior layers (Metaxas and Merideth, 1983). The inner and center section of wood veneer dries only after the MC from the outer zones has been removed completely (Peyskens *et al.*, 1984).

In contrast, microwave drying depends on the dielectric properties of woods, microwave energy, which is dispersed in the form of an electric field, is absorbed by water and wood molecules. It causes molecular friction among free and bonded water molecules and wood substance (cellulose and lignin) molecules as well. This process is known as polarization (Barnes *et al.*, 1976; James, 1977; and Peyskens *et al.*, 1984). The polarity of water molecules is higher than that of wood substances. James (1977) points out that applying an external electric field to wood causes charged-carriers to migrate through the amorphous region of cellulose and accumulate on the interface of crystalline cellulose. This results in a heterogeneous and discontinuous structure of wood cellulose.

In microwave drying, the wettest spots on the veneer sheets dry faster due to having higher dielectric properties. This is confirmed by the finding in this study that the MC profiles of the two-veneer thickness dried by microwave achieved a higher degree of moisture uniformity in comparison to those dried by conventional drying.

Microwave drying provided a high final moisture profile uniformity (the same mean MCs for outer and center sections) for both dried veneer *A* and *B*. Conventional drying resulted in a 2% variation between for veneer *A* and *B*. The variation in final moisture recorded from this work is in agreement with Torgonikov and Goriev (1995), who dried 0.75~1.15 mm Birch veneer with an initial moisture content (IMC) of 10~30% at 100~200^{o}C with 2.5 kW microwave power for 3~70 sec of drying time. Subarudi (1996) also reported a final MC variation of 2% for drying 3 mm Radiata pine veneer dried with an IMC of 133% and microwave energy of 1~2.5 kW for 9.2 minutes. The wide range of final MC profiles found following conventional drying probably arises because of non-uniformity in initial MC of both veneer thickness. Resch *et al.* (1970) found that the different of characteristics obtained for microwave drying is probably due to differences in wood specific gravity and moisture distribution.

The proportion of earlywood or latewood or a mixture on veneer *A* maybe also contribute to the non-uniformity in final MC profile. Resch *et al.* (1970) found the widest range of MC variation in Hemlock and White fir veneer due to the absence of any segregation into sapwood and heartwood. Norimoto (1978) *cited by* Peyskens *et al.* (1984) stated that anisotropic behavior of longitudinal versus transverse shrinkage in veneer of *Pinus dusiflora* was due to three factors, namely the percentage of late wood, the ratio of cell wall areas to cell areas, and the irregular arrangement of cells.

In terms of drying time, the microwave dried both veneer thickness much faster than conventional drying. Microwave drying achieved a drying rate 2.9 times faster than conventional drying for veneer *A* and a rate of drying 5 times faster for veneer *B*. The longer drying times recorded for conventional drying for veneer *A* is more influenced by the relative mix of earlywood and latewood, grain direction and veneer thickness rather than the initial MCs of wood veneer. Contrary to the view that higher MC should give faster microwave drying, the results indicate that the microwave dries veneer *B* (which had a lower GMC) dried faster under microwave than veneer *A*, which had a higher GMC. James (1977) pointed out that as the amount of water in the wood matrix increases that increases the dielectric values and provides the polar components of the cell walls and cellulose get more freedom in rotating. Peyskens *et al.* (1984) stated that a positive linear relationship is found between density and dielectric constant. However, these workers also concluded that the effects of wood MC and grain direction on the dielectric properties are also species dependent.

The drying times recorded for this work are shorter than those reported by Subarudi (1996). He found an average drying time of 9.2 minutes using 1~1.25 kW microwave power to dry 3 mm thickness Radiata Pine veneer with an IMC of 133% by flattening the veneer in the microwave cavity. However, the drying time recorded in this experiment is much longer when compared to those reported by Torgonikov and Goriev (1995). These workers obtained drying times of 3~70 sec for drying 0.75~1.15 mm thick Birch veneer with IMC's of 10~30% dried using microwave power of 2.5 kW and combining hot air temperatures of 100~200°C. Olson and Arganbright (1983) achieved drying times of 2.1~4.4 minutes for drying 3.6 mm Sweetgum (*Liquidambar stryaciflua* L.) veneer with an IMC of 110 by using microwave power of 1~15 kW combined with hot air ranging from 93~204°C.

Whilst the veneer thickness of 3 mm veneer (A) had an average of GMC value higher than those of the 1.5 mm veneer (B), the microwave energy efficiency was two times higher for veneer A samples. This may be attributed to the higher moisture content of veneer A samples and the higher wood dielectric properties and therefore more efficient microwave energy absorption by the wood veneer. Resch *et al.* (1970) reported that at high moisture contents, the wood veneer absorbs all microwave energy, while at lower veneer the moisture contents, only a portion of the energy is absorbed by wood. The remainder is absorbed by the water load. The drying times for microwave veneer drying depend on the wood species, veneer thickness and GMC. These workers also pointed out that wood would absorb twice as much microwave power at 15% moisture content than at 7%, three times at 22%, and four times at moisture content close to the fiber saturation point (FSP).

In addition, Resch *et al.* (1970) indicated that microwave drying in combination with hot air impingement would produce a double effect in which the rapid dielectric heating will vaporize wood moisture, which the hot air will remove immediately from the veneer surface. The hot air also prevents heat loss to the environment.

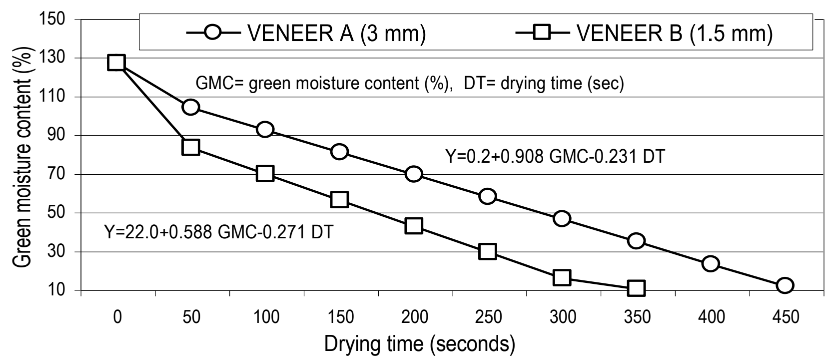

Figure 6. Rates of drying of 3 mm and 1.5 mm thick veneer following microwave drying.

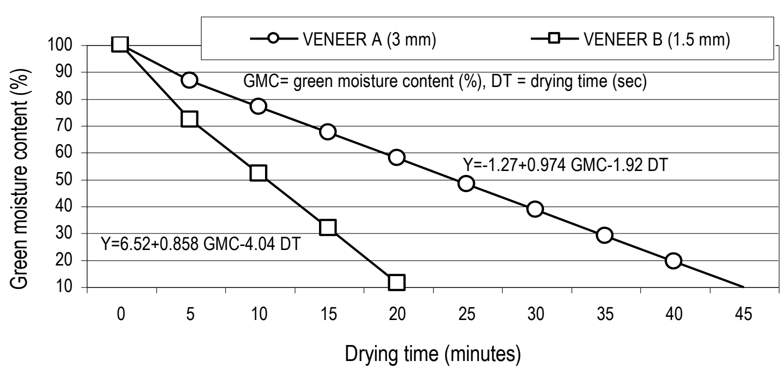

Figure 7. Rates of drying of 3 mm and 1.5 mm thick veneer using conventional drying.

In terms of drying rate, microwave drying resulted in a higher rate of drying 4 and 7 times higher than conventional drying of *A* and *B* veneer samples respectively. Even though veneer *A* had a higher GMC, the rate of drying of veneer *B* is higher. This is probably related to the presence of early wood and late wood, spiral grain/grain orientation, wood knot and veneer thickness rather than GMC effect.

Lin (1967[a]) found that the heterogeneity in gross anatomy of softwood is more important in influencing wood conductivity. This is because softwoods have very distinct density gradients in the growth rings and more compression wood nears the knots than hardwoods. He also concluded for softwood that the resistivity across the grain was 2.3~4.5 higher than along the grain. Therefore, the dielectric properties of wood also vary between radial and tangential direction (Lin, 1967[b]).

Peyskens *et al*. (1984) reported that the dielectric constant for Pine is rather higher in the transverse direction (particularly from equilibrium moisture content (EMC) to the saturated condition), while the tangential values for Pine are somewhat higher than the radial (particularly at higher moisture contents). Martin *et al.* (1987) also reported that wood characteristics in terms of density, MC, grain orientation/direction, etc. influenced microwave parameter such as phase, attenuation and degree of polarization.

The influence of veneer thickness on the rate of drying using conventional drying is significant. The thicker the veneer, the slower the drying rate becomes. Veneer *A* dried using conventional drying was 2 times slower in drying rate than veneer *B*. The evaporation processes for conventional drying are slower in the thicker veneer because it takes more time to conduct heat compared to the thin veneers (Metaxas and Merideth, 1983).

Figures 6 and 7 illustrate the behavior of 3 mm and 1.5 mm thick veneer during drying when dried by microwave and conventional drying respectively. A similar pattern of drying rates for 3 mm and 1.5 mm veneer was found for microwave drying. During the early stages of drying, the drying rate of both veneer thickness is faster, and then decreases gradually, as the MC reaches the fiber saturation point (FSP). Below FSP, the drying rate continues to decrease steadily.

Peyskens *et al.* (1984) described the behavior of polarity of wood substances, particularly the hydroxyl groups, during microwave drying. At MCs above FSP, the polar component of cellulose and cell wall compounds has more freedom in rotation when the electric fields are applied. This rotation is maximum at FSP. Below this point, rotation is eliminated as free water has been completely removed and bonded water starts to evaporate.

James and Hamill (1965), who measured the dielectric properties of Douglas fir at 1.3 and 8.53 GHz microwave frequency, reported that the dielectric constant at all frequencies increases with increasing MC, and gradually reduces as the MC falls below FSP.

Figure 7 illustrates the rate of drying of 3 mm and 1.5 mm thick Radiata pine veneer by conventional drying. They differ from those recorded for microwave dried samples. In conventional drying, veneer *B* had a higher drying rate compared to veneer *A*. It seems that veneer thickness has a significant effect on conventional rates of drying, whereas it is not significant for microwave veneer drying (Figure 6).

Conclusion

Microwave drying provided a higher final moisture profiles (more uniform), while conventional drying resulted in a 2% variation of final moisture profiles for both veneer thickness. In terms of drying times, microwave dried wood veneer 2.9~5 times faster than conventional drying. The rates of drying of microwave are 7 and 4 times higher than conventional drying for the thick and thin veneer respectively.

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