WET POCKETS IN KILN-DRIED *GMELINA ARBOREA* LUMBER

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MOYA, R. R. & MUÑOZ, F. A. 2008. Wet pockets in kiln-dried *Gmelina arborea* lumber. In drying *Gmelina arborea* there are usually great differences in the final moisture content (MC_f) between and within boards. In this research, the causes for the unevenness of MC_f were studied. Wood from two young plantations (six years old) and two older plantations nearing rotation age, i.e. 10 to 12 years were sampled. The large variation in MC_f was caused mainly by wet pockets (WP). WP were located in the heartwood area and not in the sapwood. WP were present in 37.2% of the dried heartwood boards. Mean MC_f in the cross section of boards varied between 15 to 35% and humidity in the WP exceeds 60%. WP were present in the radial orthotropic direction in 31.2% of the boards and only 1.6% in the tangential orthotropic direction. Logs from the lower part of the tree were more likely to produce WP compared with logs from the upper part, which had only less than 10% of the total WP. Young trees showed less WP incidence than older trees. The results suggested that the presence of wetwood, i.e. wood infested by anaerobic type bacteria was responsible for the formation of WP.

Keywords: Drying process, moisture content, wetwood, heartwood, sapwood

MOYA, R. R. & MUÑOZ, F. A. 2008. Saku basah dalam kayu *Gmelina arborea* yang dikering dalam tanur. Proses pengeringan *Gmelina arborea* selalu berkesudahan dengan perbezaan besar dalam kandungan lembapan akhir (MC_f) dalam papan yang dihasilkan. Dalam kajian ini kami menyelidik ketidakseragaman MC_f. Kayu daripada dua ladang yang berusia enam tahun serta dua ladang lain yang lebih tua dan menghampiri usia pusingan (11 hingga 12 tahun) disampel. Saku basah (WP) merupakan faktor utama yang menyebabkan perbezaan besar dalam MC_f. WP terletak dalam teras kayu tetapi tidak dalam kayu gubal. WP wujud dalam 37.2% papan teras kayu kering. Min MC_f dalam keratan rentas berbeza antara 15% hingga 35%. Sementara itu kelembapan WP adalah melebihi 60%. Sebanyak 31.2% papan mempunyai WP dalam arah ortotrop jejari dan hanya 1.6% papan dalam arah ortotrop tangen. Kayu daripada bahagian bawah pokok lebih cenderung menghasilkan WP berbanding kayu daripada bahagian atas pokok yang cuma mempunyai 10% WP. Pembentukan WP kurang dalam ladang yang lebih muda berbanding ladang yang lebih tua. Keputusan kajian menunjukkan bahawa kehadiran kayu basah iaitu kayu yang dijangkiti bakteria jenis anaerobik menyebabkan pembentukan WP.

INTRODUCTION

Gmelina arborea (melina) is widely used in commercial reforestation programmes in tropical countries for sawn wood production, pulp or bioenergy (Dvorak 2004). Despite its great success as raw material, problems arising from its drying process have caused this species to be unpopular in commercial reforestation programmes (Lauridsen & Kjaer 2002). Drying is an important process in manufacturing for it contributes to dimensional stability, compatibility of coatings and adhesives, improvement of workability, thermal, acoustic and electrical insulation and also to the increase in mechanical and biodegradation resistance (Haygreen & Bowyer 1996).

Dried melina wood presents few defects such as warping, checking, splitting and collapse but a great difference in the wood final moisture content (MC_f) is of great concern. Few studies have described the causes for variation in wood moisture content (MC) of *G. arborea*. Sattar *et al.* (1991) studied the correlation of wood quality with different drying schedules while Muñoz & Moya (2007) established that MC_f is statistically affected by the position of the board between the pith and the bark, anatomical variation, the presence of sapwood and specific gravity.

Wet pockets (WP), also known as water pockets, are found in dried wood of some species. WP are zones with 10% or higher than

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average moisture content (Simpson 1991). These are zones that can be seen on the cross section and might extend for a large portion through the width and length of boards. Regions near WP are associated with defects by differences in shrinking such as crook, bow, twist, cup, checks or split (Simpson 1991). Boards showing this condition are rejected in manufacturing processes because of their poor performance during product manufacturing. If MC_f of wood in use is higher than the equilibrium moisture content (EMC), furniture, doors, shelves or other types of products are going to lose adhesion in joints or they may twist in reaching the EMC with the environment where WP are present (Simpson 1991).

Due to lack of information to explain the causes for the variations of MC_f in melina wood after kiln drying process, this research examined the occurrence of WP in dried lumber. Other factors such as saw pattern, tree age, climatic conditions, position in tree height and orthotropic directions (tangential and radial) were evaluated to measure their influence on MC_f in dried lumber.

MATERIALS AND METHODS

Plantation sites

Melina trees were fell from fast-grown plantations in two different Costa Rican regions, namely, North Pacific (NP) and South Pacific (SP). The NP region has an annual average temperature of 28 °C and 2000 mm year^{-1} of precipitation with well defined rainy and dry seasons. The SP has an average precipitation of 4000 mm year^{-1}, dry season between December and April and a mean annual temperature of 26 °C (Mena 2006).

Materials

Two plantations were chosen from each region, one young plantation under six years old and another, near the rotation age of 10 to12 years. Each plantation was codified according to different regions so young plantation in NP with NP1, older plantation in NP with NP2, young plantation in SP with SP1 and older plantation in SP with SP2 (Table 1). NP1 and NP2 plantations were planted using pseudo-cutting method. SP2 came from a seed stand while SP1 plantation was a genetically improved cloned plantation. Two plots (400 m^2) were established to characterize the plantation (Table 1). Nine trees were selected to represent all the diameter range in the plantation. Special care was taken to select trees having straight trunks, without bifurcations but with normal branching and without any visible disease or pest symptoms. From each selected tree, two logs of 2.5 m long were obtained, one from the tree base (lower log) and the other from the uppermost commercial log (upper log). For NP1 it was not possible to obtain upper log because only one commercial log was cut due to the low height of the trees.

Sawing pattern

Logs were sawn using a pattern described in Figure 1(a). This pattern was designed to produce boards with different orthotropic directions (Figures 1c–f) commonly used in Costa Rica to obtain wood for furniture industry. Each board was 2.5 cm thick and boards with bark were processed using an edger. Each board was properly identified by climatic condition, height and tree number. A total of 247 boards were obtained from 56 logs of melina.

Table 1 Location and characteristics of melina plantations used in the drying process

Sample area	Code	Age (years)	Plantation density (trees/ha)	Geographic location	Average area basal (m^2/ha)	Volume (m^3/ha)	Average tree height (m)	Average dbh (cm)
South Pacific	SP1	6	710	N10° 47' 19" W83° 57' 07"	26.0	181.2	19.5	20.7
	SP2	12	368	N10° 47' 19" W83° 57' 07"	23.1	228.5	25.1	28.0
North Pacific	NP1	5	1025	N09° 56' 24" W85° 08' 30"	17.1	88.4	14.5	14.7
	NP2	10	341	N11° 53' 10" W86° 35' 34"	27.9	280.2	25.0	30.7

dbh: diameter at breast height

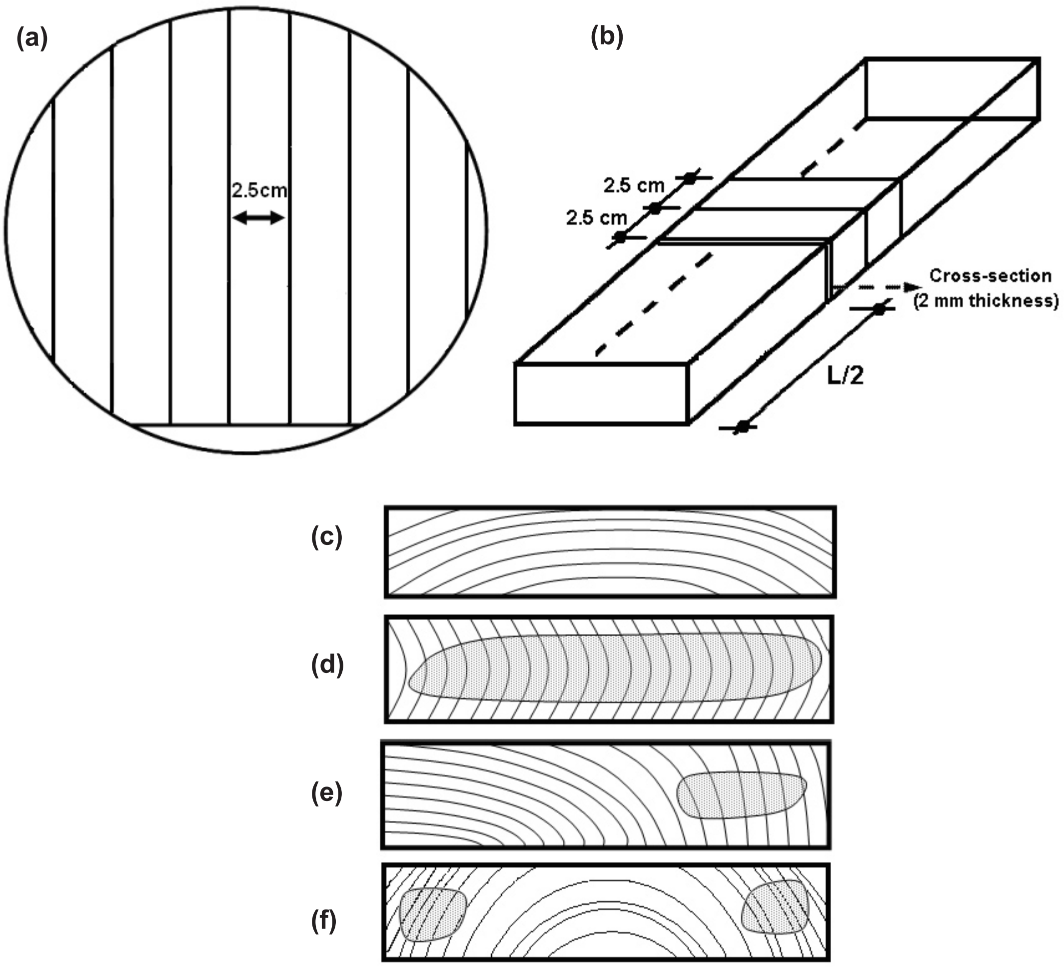

Figure 1 (a) Pattern saw used to obtain lumber; (b) sample preparation to determine the presence of wet pockets (WP) and moisture content; (c)–(f) different kinds of grain patterns with WP (shaded) after the drying process in relation to the sawing pattern

Board classification

All 247 boards were classified by their grain pattern viewed in cross section: (1) board with tangential orthotropic direction (FS) (Figure 1c), (2) board with radial orthotropic direction (QS) (Figure 1d), (3) board with two combined orthotropic directions, radial-tangential (CQF) (Figure 1e), and (4) board in three combined orthotropic directions, radial-tangential-radial (CQFQ) (Figure 1f).

Drying

The drying process was carried out in a small NARDI® 2 m^3-capacity dry kiln. The drying schedule used was that which is frequently used by operators in Costa Rica, i.e. mild with relatively low temperatures and high humidity at the beginning of the drying process, allowing for a high EMC into the kiln and decreasing with time (Figure 2). Total drying time was 288 hours. Each board was evaluated for the presence of defects such as warping, bow, crook, twist, cup, drying checking and split before starting the drying process. Methods suggested by Hallock and Malcolm (1972) and Milota (1996) were followed for measuring drying defects.

Moisture content control

The pilot kiln had six moisture probes, which were located at different heights and depths of the package. These probe measurements were used as reference to make changes to both the temperature and relative humidity inside the kiln. MC was also monitored using six kiln samples located at different pile heights.

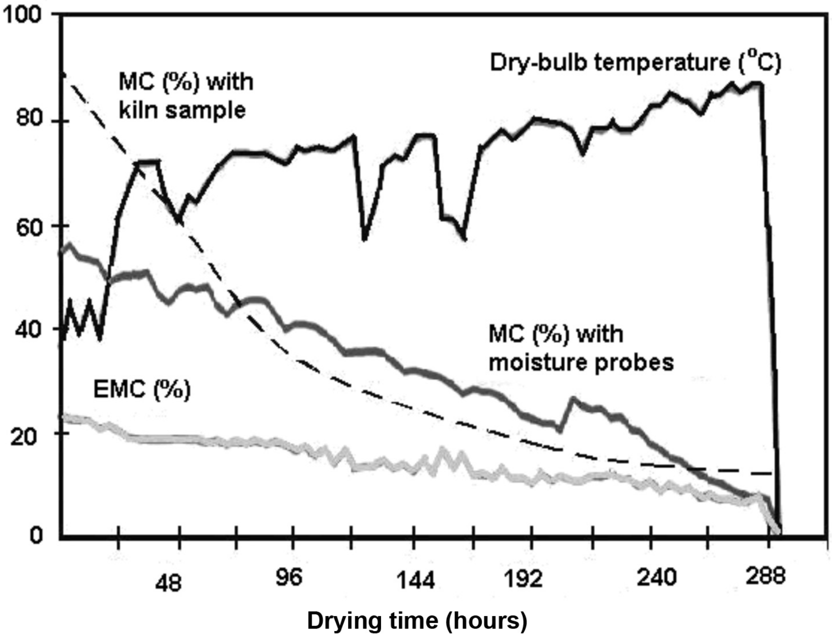

Figure 2 Variation of equilibrium moisture content (EMC), temperature and moisture content (MC) of wood during drying process

Wet pocket evaluation in dried lumber

After the drying process each board was evaluated for the presence of bow, crook, twist, cup, splits and collapse. A cross section (1.5–2.0 mm thick) was then cut at the middle of the board length (Figure 1b) with a 300 cm-diameter circular saw, tipped with tungsten carbide teeth, 18 mm-tooth spacing (pitch), and 48 teeth of 3 mm thickness and 10 mm height. Cross sections were inspected against the light for internal checks (honey comb) and ring failure while the presence or absence of WP was evaluated on thin cross sections following the methodology suggested by Coutts and Rishbeth (1977). Regions with moisture concentrations, for example in WP, appeared translucent against the light while areas without, opaque. WP were located in the tangential or radial orthotropic directions inside the board. Sample comprising 15% boards with problems of WP were selected randomly. Two strips 2.5 cm long (Figure 1b) were cut from each board section. One of the strips was used to measure mean MC of the cross section and the other, to obtain internal MC of WP. WP outline was marked and a digital picture was taken before oven drying the sample. WP area was determined by using Image Tool Software® (Health Science Center 2006).

WP wood was quickly separated from sample boards to avoid moisture loss using a vertical band saw. All samples with WP were weighed and dried in an oven at 103 ± 2 °C for 24 hours to determine the MC (ASTM 2003).

RESULTS

Production of boards

In every condition evaluated (region, heights and ages) boards with four established grain pattern types were found, except for logs from NP2 which only had boards with FS, CQF and QS (Table 2). Logs from the upper part of trees had the highest proportion of FS-type boards (41 to 48%). However, CQFQ-type boards were the lowest (0) for lower NP2. These boards were obtained from lower logs of NP2 plantation (Table 2). QS-type board percentages were low, not exceeding 26%. The amount of FS boards from lower logs of SP2 and NP1 plantation reduced to 23 and 26% respectively and QS in CQFQ increased to 44 and 52% respectively. In this case, the log diameters ranged from 8.5 to 30 cm (Table 2).

Table 2 Boards obtained with four different types of grain patterns for the two different origins, ages and tree heights

Zone	Part of tree	Quantity of logs	Average diameter (cm)	Heartwood (%)	Grain pattern			
					FS	CQF	QS	CQFQ
SP1	Lower	9	16.19 (14.0–20.0)	67.91	42	19	26	13
	Upper	9	12.86 (10.5–15.0)	64.23	48	31	14	7
SP2	Lower	9	25.56 (21.5–30.0)	67.63	23	19	14	44
	Upper	9	16.75 (13.5–21.0)	66.56	47	30	17	7
NP1	Lower	9	10.00 (8.5–11.0)	0.00	26	15	7	52
	Upper	-	-	-	-	-	-	-
NP2	Lower	8	24.63 (22.0–28.0)	66.71	41	47	12	0
	Upper	8	19.06 (15.5–22.0)	64.13	41	22	24	14

SP1 = South Pacific, young plantation; SP2 = South Pacific, old plantation; NP1 = North Pacific, young plantation; NP2 = North Pacific, old plantation

FS = board with tangential orthotropic direction; QS = board with radial orthotropic direction; CQF = board with two combined orthotropic directions, radial-tangential, CQFQ = board in three combined orthotropic directions, radial-tangential-radial

Presence of wet pockets

WP were not present if the board edge was sapwood. WP were found in 32.8% of total boards (247), with large variations in areas and shapes. MC evaluation inside wet regions in dried wood showed that values varied from 40–100% (Figure 3a). Nevertheless, final average MC of cross sections varied from 15 to 35% depending on the WP area (Figure 3b).

The percentages of WP in trees from older plantations were very similar. Wood from NP2 and SP2 showed 39.8 and 36.8% of all boards with WP respectively (Figure 4a).The board section with radial orthotropic direction produced most of the WP for SP2 and NP2, with values of 36.8 and 38.6% respectively. These numbers are far larger than 2.3 and 1.2% (Figure 4b) found in sections with tangential orthotropic direction of boards from SP2 and NP2 respectively.

Boards with radial orthotropic direction (QS, CQF and CQFQ) were most likely to generate WP at the end of the drying process. In 35.2% of the boards, WP were present in the radial orthotropic direction, unlike the tangential orthotropic direction in which only four (2.43%) boards were found (Figure 4b).

The amount of dried board samples with WP is lower in trees from younger plantation, i.e. 23.3% in SP1 (Figure 4a). No WP were present in NP1. As with younger plantations, radial orthotropic direction was again more likely to produce WP in older plantations as well. From the 21.7% of boards from SP1 that produced WP, only 1.7% were tangential orthotropic direction wood (Figure 4b).

Lower part of trees produced more boards having WP. The difference between the upper and lower trunk was large, except those from SP2 where lower log was superior to upper log (Figure 4c). Tree height variation also showed that boards with radial orthotropic direction were likely to produce WP than boards with tangential orthotropic direction (Figure 4c).

Wet pockets in relation to grain pattern

FS boards had the least incidence of WP (Table 3), i.e. only 4.5%. On the contrary, QS, CQF and CQFQ lumber presented greater percentages of incidence. Older plantations, i.e. NP2 and SP2 showed the largest incidence of WP, with 60 and 80% respectively (Table 3). CQFQ boards were prone to produce WP with an average of 66.1%, i.e. 75.7% in NP2, 33.3% in SP1 and 55.6% in SP2 (Table 3). These values were similar to QS-type boards. On the other hand, CQF boards produced few WP in comparison with FS and QS grain. A total of 20.5% of the CQF boards presented WP problems.

Presence of drying defects

Crook, twist, cup, checking, split and collapse increased with degree of drying but bow decreased for boards with or without WP (Table 4). Cup, split and collapse increased with the presence of boards with WP but bow, on the other hand, decreased. Crook, twist and drying checking were not affected by the presence of WP (Table 4). Honeycomb was only present in

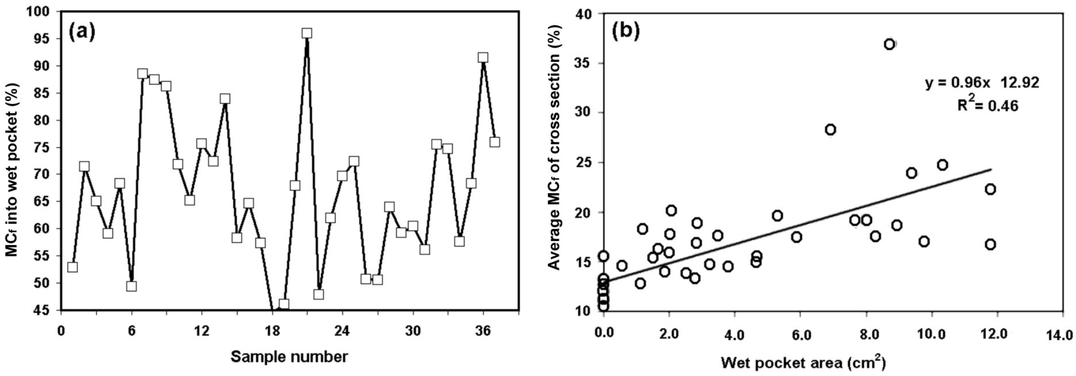

Figure 3 MC$_f$ (%) into wet pocket in dried melina wood and MC$_f$ (%) average variation of the cross section in relation to the WP area

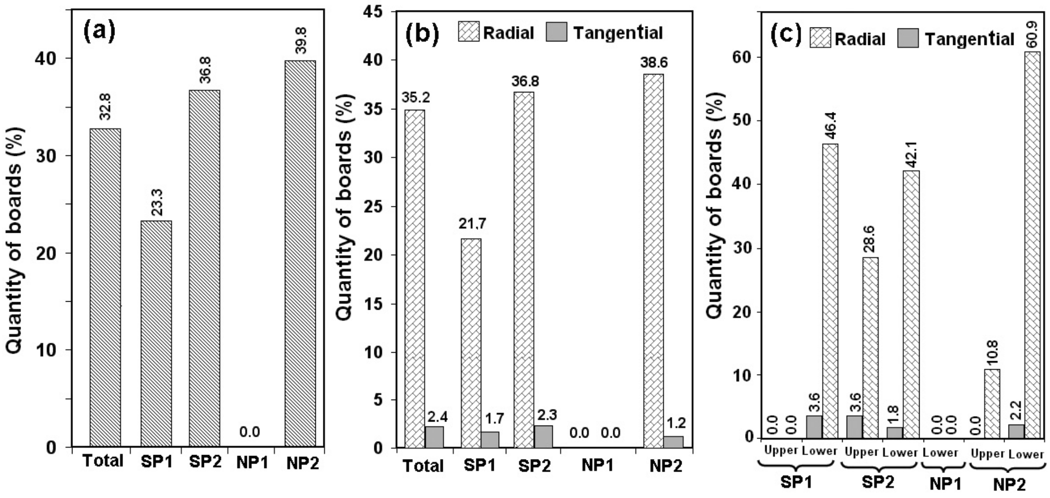

Figure 4 WP presence in dried melina wood and its incidence according to the type of orthotropic direction, climatic condition and tree height

Table 3 Percentage of WP in dried wood of *G. arborea* according to grain pattern types for the different origins and ages

Grain pattern type	NP1		NP2		SP1		SP2		Total	
	Boards with WP (%)	Quantity of boards	Boards with WP (%)	Quantity of boards	Boards with WP (%)	Quantity of boards	Boards with WP (%)	Quantity of boards	Boards with WP (%)	Quantity of boards
FS	0.0	7	3.7	27	3.7	27	7.4	27	4.54	88
QS	0.0	8	60.0	15	33.3	15	80.0	20	57.41	58
CQF	0.0	2	8.3	12	50.0	12	7.69	13	20.51	39
CQFQ	0.0	0	75.7	29	33.3	6	55.6	27	66.13	62

SP1 = South Pacific, young plantation; SP2 = South Pacific, old plantation; NP1 = North Pacific, young plantation; NP2 = North Pacific, old plantation

FS = board with tangential orthotropic direction; QS = board with radial orthotropic direction; CQF = board with two combined orthotropic directions, radial-tangential, CQFQ = board in three combined orthotropic directions, radial-tangential-radial

Table 4 Defects in dried melina wood observed in this study before and after drying

Defect type	Before/after drying	Wood without WP	Wood with WP
Crook (mm)	Before	4.32	3.03
	After	5.06	4.63
Bow (mm)	Before	14.33	9.33
	After**	8.00	7.33
Twist (mm)	Before	0.18	0.00
	After	1.00	1.19
Cup (mm)	Before	0.00	0.00
	After**	1.58	3.03
Checks length (mm)	Before	7.13	9.16
	After	9.92	11.05
Split length (mm)	Before	1.40	2.03
	After**	22.70	63.65
Boards with collapse (%)	Before	0	0
	After**	3.61	16.05

** Significant difference between wood with and without WP after drying
The quantity of boards evaluated was 170 wood without WP and 77 with WP.

six out of the 247 boards evaluated, three each for boards with and without WP. On the other hand, wood with or without WP was free from ring failure.

DISCUSSION

Several studies suggest that the presence of WP is attributed to the presence of wetwood (Ward 1986, Ward & Pong 1980, Simpson 1991). The formation of wetwood has been attributed to an anaerobic type bacteria invasion in the heartwood (Worrall & Parmeter 1982, Schink & Ward 1984, Jeremic *et al.* 2004). Low permeability, slow drying rate and drying defects are the characteristics related to wetwood (Jeremic *et al.* 2004, Cai 2005).

Even though wetwood presence in melina is not reported in the literature, some problems have been noted. Moya (2002) could not relate the presence of a light coloured wood near the pith with physical, anatomical or mechanical properties of melina. Nevertheless, in a recent research we observed that wetwood was found in melina trees (Muñoz & Moya 2007).

MC values of WP in this study were over 60%, which indicated that moisture still remained inside the board. Nevertheless, the average MC in transversal section was very much lower, i.e. between 15–35% depending on the area covered by the WP (Figure 3). Ward (1986), working with *Abies concolor, Populus tremuloides* and *P. grandidentata*, found that the regions with wetwood in dried boards had MC values of 35.0–36.4%. These results concurred with our results for melina boards with WP.

The excess moisture found in WP may present problems when measuring MC (Ward 1986). Dielectric moisture metres could not give accurate measurements of still moisture regions (Kozlik 1971). Recently, new techniques have been developed to detect WP in wood, such as waves spreading, dielectrical materials, chemical analysis, oxygen sensors, acoustic-ultrasonic emission analysis, mass spectrometers and detection by x-rays and ultrasound (Kabir *et al.* 2006, Pettersen *et al.* 1993).

WP formation was limited principally in a section of the board composed by wood of radial orthotropic direction (Figure 4 and Table 3). Figures 1(c)–(f) showed the possibility of finding WP in relation to the sawing pattern on dried lumber. In QS boards all cross sections were susceptible to WP formation. In CQF (Figure 1e) and CQFQ boards (Figure 1f) parts with radial orthotropic direction, located on one side or on both sides of the board, were more likely to produce WP. Lumber with tangential direction was less prone to form WP.

Two possible explanations for WP formation in dried wood with radial orthotropic direction could be explained by the following hypothesis:

1. (1) High values of capillary forces during the initial drying process produces aspiration of pits. Both tangential and radial orthotropic directions show different water movement speeds (Pang 2002, Chauhan & Aggarwal 2004). The anisotropy is due to the different

orientation of cell elements in wood (Haygreen & Bowyer 1996). In boards with tangential orthotropic direction the steam flow or water diffusion occurs by rays, while in the radial orthotropic direction, the movement occurs through fibre pits which are located generally on the radial face (Pang 2002). At the beginning of the drying process pits can produce strong capillary forces resulting in margo aspiration and, thus, not permitting the flow of vapour (Sattar *et al.* 1991).

(2) For QS, CQF, CQFQ lumber, water movement in the board section with radial orthotropic direction occurs mainly through the fibre pits which are scarce and minute (Moya *et al.* 2007). Aspirated and encrusted pits are present in wetwood because bonding strength in middle lamella for wetwood is often weaker than for normal wood (Lihra *et al.* 2000, Jeremic *et al.* 2004). Both conditions, i.e. scanty and aspirated pit conditions do not allow the flow of water vapour in lumber with radial orthotropic direction which produces WP. Wetwood is not present in sapwood (Ward & Pong 1980, Xu *et al.* 2004). Our results confirmed this where boards with radial orthotropic direction and sapwood did not have WP.

WP incidence increased with higher percentage of heartwood in the sampled trees. The amount of heartwood was small in melina younger plantations, i.e. 0% for NP1 and 64.2% for SP1. However, these percentages increased in older plantations, 67.3 and 66.7% in SP2 and NP2 respectively (Table 2). The same trend was shown in boards with WP after the drying process (Figure 4a). It is, thus, suggested that WP originate from wetwood developed in the heartwood.

The different region of Costa Rica showed that the highest incidence of WP occurs in logs from the lower part of the older trees (Figure 4c). Studies for different species have shown that this type of wetwood is formed frequently in older trees (Ward & Pong 1980, Ward 1986). Wetwood was developed in the lower part of trees of *Abies* sp., *Pinus* sp., *Tsugas* sp., *Populus* sp., *Acer* sp. and *Quercus* sp. as a result of root infection by anaerobic bacteria or injuries produced in the tree (Ward & Pong 1980).

Defects such as bow, cup, collapse and split were caused by WP (Table 4). Drying defects together with drying time are the most severe problems associated with the presence of wetwood (Ward & Groom 1983, Verkasalo *et al.* 1993). Bacterial enzymes able to degrade hemicellulose and pectins in the middle of cell walls are associated with the occurrence of check, honeycomb and collapse (Ward & Pong 1980).

CONCLUSIONS

Orthotropic directions influence the formation of WP in dried wood of *G. arborea*. Boards with radial orthotropic direction are more susceptible to produce WP than boards with tangential orthotropic direction. QS boards are more likely to produce WP. Boards with CQF and CQFQ grain patterns are also likely to produce WP but only in those with radial orthotropic direction. WP are almost exclusively associated to boards with heartwood. In addition logs from the lower part of trees have higher percentage of boards with WP compared with upper part of trees.

This study evaluated the presence of drying defects. There were statistical differences in boards with WP for bow, cup and for the presence of splits and collapse. Bow was the only defect that decreased in boards with WP. Crook, twist and checks were not affected by WP in melina dried lumber.

The WP present in melina dried boards are the main cause for the lack of uniformity in the final MC. MC values of boards with WP varied between 15 and 40%. However, the WP inner region had MC exceeding 60%. Wetwood presence in melina suggests that it is the main cause for WP formation during the drying process. Low permeability, slow drying rate and modifications in the anatomical elements associated to water flow inside the wood are related to wetwood.

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