A Study on Moisture Distribution of Green Wood and Variations of Specific Gravity in *Crytomeria japonica* D. Don

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【Summary】

This study deals with the distribution of moisture in green wood of standing trees of planted *Crytomeria japonica* D. Don. The radial and longitudinal variations of specific gravity, volumetric shrinkage, and tracheid length were also investigated. Two trees of about 43 yr of age were sampled from Shanping Station, Liukuei Research Station, Taiwan Forestry Research Institute. The results show that both wet wood and dry wood were present in the stems of the sampled trees. The moisture content of wet wood area is rather high, even reaching its moisture saturation point in heartwood. The dry zone area occurs in the sapwood adjacent to the boundary of the heartwood. The degree of saturation in the dry zone is only 1/2 to 1/3 that of wet wood. The specific gravity of wood increases from the stump upward to the crown. The percentage of volumetric shrinkage correlates positively with specific gravity, while the moisture content shows a negative correlation with specific gravity. The tracheid lengths increase from the pith outward to a maximum during the maturation of the wood, after which the length remains approximately constant.

Key words: specific gravity, moisture content, volumetric shrinkage, degree of saturation, maceration.

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柳杉生材水分分布及比重變異之探討

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摘　要

本研究乃探討柳杉(*Cryptomeria japonica* D. Don)造林木之含水率(moisture content)、比重(specific gravity)、體積收縮率(percentage of volumetric shrinkage)及管胞長度(tracheid length)縱向及橫向變異。試樣二株，約43年生，採自台灣省林業試驗所六龜分所、扇平工作站。由結果顯示柳杉生材水分隨樹高之上升而下降，比重則隨樹高之上升而增加。在纖維飽和點下，木材乾燥時體積收縮率與比重成正相關。水分之徑向分布顯示明顯的乾材與濕材帶，心材與邊材間之移行材(intermediate wood)在立木狀態下之水分梯度突降，邊、心材皆以濕材呈現，有別於一般乾燥心材。而管胞長度則由髓心往樹皮處增加，至一最大值後，即不再明顯增加，顯係已達成熟齡。

關鍵詞：比重、含水率、飽和度、體積收縮率、解析。

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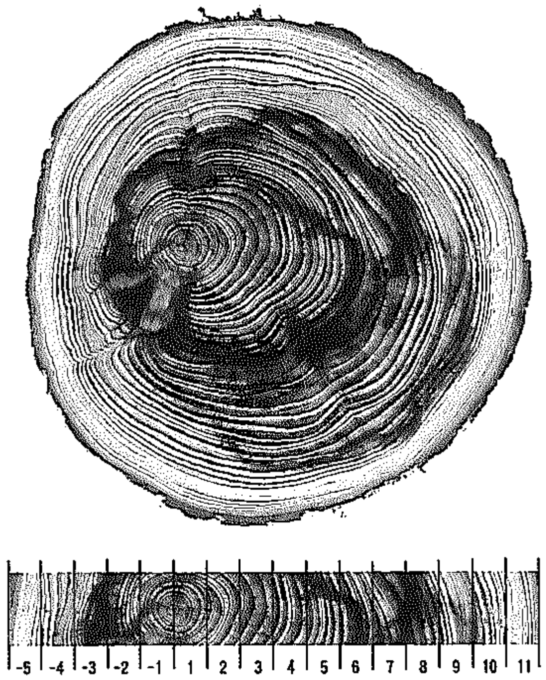

Fig. 1. Breakdown of sample blocks from a disk.

INTRODUCTION

The study of the distribution and variation of wood moisture content in green wood and specific gravity of Crytomeria japonica D. Don is part of "Study on growth stresses in trees" which is one of the research projects under the supervision of the National Science Council (No. NSC 86-2313-B054-002). The features concerning wood properties such as anatomical, physical, mechanical, and chemical properties in the tree trunk will be fully investigated and reported separately.

During the investigation of some fundamental physical properties, an interesting phenomenon happened when a tree trunk was cut down from the standing tree. Some dry and somewhat non-transparent white areas were observable in the transition zone of sap- and heartwood. These dry zones, so-called white zones, are not common in conifers except when trees are suffering from infection by bacteria or fungi as reported by Cutts (1976). The investigation of the radial and longitudinal distribution of moisture in green wood was therefore considered in this study. The variations of degree of saturation, specific gravity, and volumetric shrinkage were also calculated for comparison.

MATERIALS AND METHODS

Two trees of *Crytomeria japonica* D. Don grown in Shanping Station, Liukuei Research Station, Taiwan Forest Research Institute were chosen and felled on 8 Oct., 1996. Three 3-cm thick disks were taken at every 1.5-m interval from 30 cm above the ground to near the crown for each tree. Then 8-mm wide specimens from each disk were sawn systematically from bark to bark through the pith (Fig. 1). This was dissected at 1-cm intervals radially for each sample strip. The diameter and number of growth rings for each disk were recorded (Tables 1 and 2). The volumes of sample blocks were measured by the water displacement method (Haygreen, 1982), thus the basic specific gravity was calculated as a ratio of its oven-dry weight (103 ± 2℃) to the weight of the displaced water (Panshin and De Zeeuw, 1980). The percentages of volumetric shrinkage were also calculated..

Specimens taken from disks at breast height were also sampled with the same processes mentioned above for the study of tracheid length variation. Each specimen was macerated by modified Franklin's method (Chen, 1992). A total of 100 tracheids was sampled randomly and measured by using a 200x magnification. The radial variation of tracheid length was used to estimate the differentiation of mature wood. The data were collected, analyzed, and graphed using software of Excel, SAS, and HWG. The general information of samples are listed in Tables 1 and 2. To highlight the dry zone areas, the degree of saturation was evaluated by the use of maximum moisture content. The calculation formula is shown as follows:

Degree of saturation = U/U_{max}

$U_{max} = 0.28 + (1.5 - \gamma_o/1.5\gamma_o)$

U: moisture content

U_{max} : maximum moisture content

γ_o: specific gravity.

RESULTS AND DISCUSSION

Table 1. Legend of the sampling disks at various heights (Tree I)

Height	Growth ring		Radius (cm)		Diameter	Sapwood (cm)		Heartwood (cm)	
(m)	a[1)]	b[2)]	a	b	(cm)	a	b	a	b
0.3	42	36	12.3	9.3	21.6	5.8	3.8	6.5	5.5
1.8	30	27	8.6	8.3	16.9	4.1	4.3	4.5	4.0
3.3	26	27	8.8	7.2	16.0	3.3	3.2	5.5	4.0
4.8	27	24	9.8	6.1	15.9	4.8	3.1	5.0	3.0
6.3	26	26	8.6	6.5	15.1	5.1	4.5	3.5	2.0
7.8	25	22	6.2	6.2	12.4	3.7	4.7	2.5	1.5
9.3	21	20	6.8	4.4	11.2	3.8	2.9	3.0	1.5
10.8	19	16	7.0	4.2	11.2	4.0	3.2	3.0	1.0
12.3	16	16	4.6	4.1	8.7	2.6	2.6	2.0	1.5
13.8	11	11	2.6	1.3	3.9	2.6	1.3	0.0	0.0

1) a = leeward side.
2) b = windward side.

Table 2. Legend of the sampling disks at various heights (Tree II)

Height	Growth ring		Radius (cm)		Diameter	Sapwood (cm)		Heartwood (cm)	
(m)	a[1)]	b[2)]	a	b	(cm)	a	b	a	b
0.3	44	37	11.0	8.4	19.4	4.5	2.9	6.5	1.9
1.8	43	33	10.9	4.2	15.1	4.4	2.2	6.5	2.0
3.3	36	37	6.9	7.3	14.2	1.4	1.3	5.5	6.0
4.8	37	32	6.7	5.0	15.9	0.7	1.5	6.0	3.5
6.3	33	29	6.7	4.0	13.7	1.2	1.5	5.5	2.5
7.8	29	26	4.7	3.4	10.7	2.2	0.9	2.5	1.2
9.3	20	18	3.6	2.0	8.1	2.1	1.5	1.5	0.5
10.8	---	---	1.7	1.4	5.6	1.7	1.4	0.0	0.0

1) a = leeward side.
2) b = windward side.

Table 3. Statistical data for the sample trees

Sample Tree	N[1)]	Mean SG_{gg}[2)]	Mean SG_{oo}[3)]	Mean SG_{og}[4)]	Mean MC[5)] (%)	Mean D.S.[6)]	Mean Vol. Shr.[7)] (%)
I	94	1.09	0.66	0.58	90.35	0.76615	12.34
II	135	1.02	0.56	0.48	116.05	0.79538	13.37

1) Number of samples.
2) SG_{gg} = specific gravity based on green weight and green volume.
3) SG_{oo} = specific gravity based on oven-dried weight and oven-dried volume.
4) SG_{og} = specific gravity based on oven-dried weight and green volume.
5) Moisture content.
6) Degree of saturation.

Table 4. Statistical data for the radial variation of sample trees

Radial position	N	Mean SG_{gg}[2]	Mean Sg_{oo}[2]	Mean SG_{og}[2]	Mean MC (%)[2]	Mean D.S.[2]	Mean Vol. Shr. (%)[2]
Outermost	37	1.11305(A)[1]	0.62200(A)	0.54118(A)	109.90(A)	0.85626(A)	12.9923(A)
Sapwood	65	0.97731(B)[1]	0.54572(B)	0.48083(B)	107.95(A)	0.70842(B)	11.8586(B)
Intermediate	22	0.94825(C)[1]	0.61844(A)	0.55103(A)	72.75(B)	0.58508(C)	10.8932(C)
Heartwood	105	1.09295(A)	0.62461(A)	0.53684(A)	109.30(A)	0.84565(A)	14.0290(A)

[1] (A), (B), (C) are Duncan groups at $\alpha = 0.05$; the same letter in a given column means no significant difference.
[2] Abbreviations defined as in Table 3.

Table 5. Statistical data for Fig. 11

M.C/Ht.	Std. dev.	Corr. Coeff.	R^2	Power regression a coeff.	Power regression b coeff.
Tree I	19.09	-0.77	0.59	4.89	-0.13
Tree II	12.77	-0.96	0.91	4.58	-0.11

Table 6. Statistical data for Fig. 12

M.C/Ht.	Std. dev.	Corr. Coeff.	R^2	Power regression a coeff.	Power regression b coeff.
Tree I	0.06	0.89	0.80	-0.70	-0.09
Tree II	0.05	0.87	0.76	-0.47	-0.07

The statistical data of specific gravity, moisture content, degree of saturation, and percentage of volumetric shrinkage are shown in Tables 3, 4, 5, and 6.

Moisture distribution

In the study of the radial distribution of the moisture content in the green wood of *Cryptomeria japonica*, a drastic difference between wet wood and the dry zone was found. As shown in Figs. 2 and 3, the moisture content in wet wood area are mostly higher than 100%, while in the dry-zone area, where color was pale when first cut from the standing tree, the moisture content obviously decreases sharply to about 1/2 to 1/3 of that of wet wood. It is even clearer when maximum moisture content of wood is concerned; the degree of saturation clearly shows the distribution of the wet wood and dry zones. Three Duncan groups at $\alpha = 0.05$ (A: outermost and heartwood, B: sapwood, C: intermediate wood) can clearly be differentiated (Table 4). The dry zone consistently exists in tree I where there is heartwood formation (Figs. 4 and 5). While in tree II, the dry zone is only prominent in samples near the stump, i.e., 0.3 m above the ground. Cutts (1977) also reported that the dry zone exists frequently in the stump of Grand fir.

The dry zone exists in sapwood adjacent to the heartwood as shown in Figs. 4 and 5. Investigating heartwood of Sugi (*Cryptomeria japonica* D. Don), Takahashii (1996) found that the moisture content of black-colored heartwood is much higher than that of normal red heartwood. Although he did not mention the moisture content of the dry zone, we could clearly notice a dry zone from the graph presented in his report. In the present study the sample trees contain irregular contours of black-colored heartwood and also reveal the same results.

In conifers, moisture content of heartwood is generally much lower than that of sapwood, and the bordered pits in heartwood are aspirated due to moisture loss during heartwood formation. However, the pit aspiration is frequently observed to be incomplete in *Cryptomeria japonica* D. Don (Fujii *et al.*, 1997). This may cause high moisture content in the wood. Hillis (1987) investigated 12 conifer species and found that *Cryptomeria japonica* and *Taxus baccata* are the only 2 species in which the heartwood moisture content is higher than 100%; other conifer species have relatively drier heartwood. He also mentioned that the moisture content of black-colored heartwood is over 200% which is almost the same as sapwood.

Hypotheses of the formation of the dry zone have been made by a few researchers. Cutts (1976) inoculated *Fomes annosus* on the stems of *Abies grandis*, and noticed that the infection leads to the formation of a dry zone after a few days. He found that water was withdrawn from infected parts of logs into uninfected parts

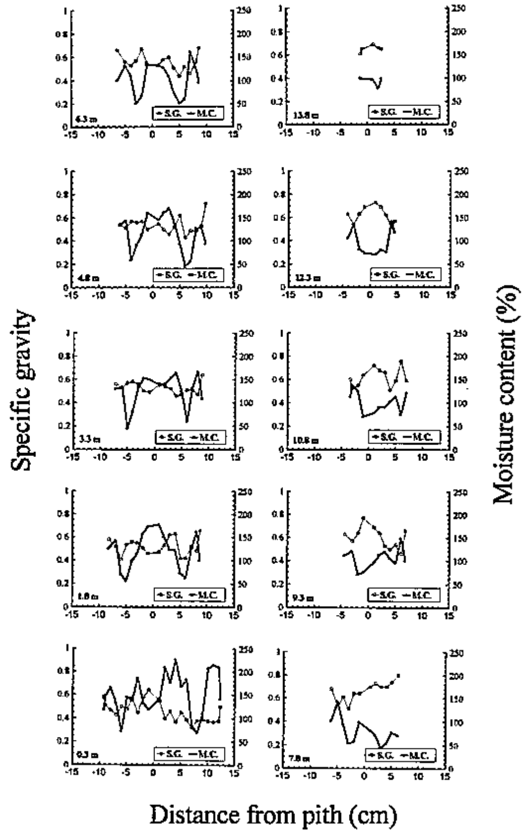

Fig. 2. Radial variations of specific gravity (S.G.) and moisture content (M.C.) (Tree I).

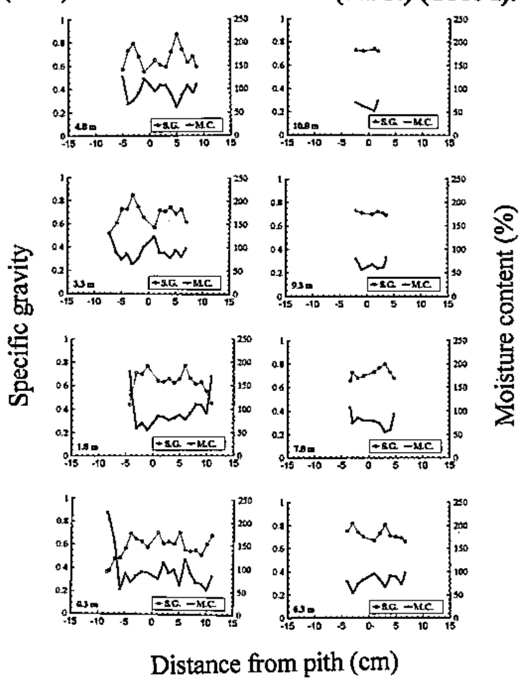

Fig. 3. Radial variations of specific gravity and moisture content (Tree II).

probably by the release of hydrostatic tension which exists in standing trees. The tori of bordered pits is damaged by enzymatic lysis, causing air paths and eventually replacing water in the tracheids. He postulated that wood substances diffusing from the infected region causes the formation of the dry zone.

Cutts (1977) also injected various toxic chemicals into Corsican pine (*Pinus nigra* var. *maritima*), Scots pine (*P. sylvestris*), and Grand fir (*Abies grandis*), and found that the dry zone only formed when temperatures were between 10 and 20℃. He postulated that the gradual death of ray cells alters their metabolism in such a way that gas emboli are evolved in adjacent tracheids; they can occur at sites of infection or at a distance under the influence of transportable or diffusible toxins.

On the other hand, the embolism of tracheids was also mentioned by Sperry (1985). During heartwood formation, the dying ray cells are deficient in food supply from the cambium since they are far from the phloem. The metabolic gas released from these dying cells penetrates into contacted tracheids causing cavitation. And thus the moisture is blocked by the aspiration of pits.

Nobuchi and Harada (1985) found that "as the changes of ray parenchyma cells take place, some structural changes also were observed in the tracheids such as the aspiration of bordered pit-pairs and the osmiophilic depositions over the inner surfaces of tracheid walls". Based on these observations, it is concluded that osmiophilically stained materials, which possibly have been transferred from ray parenchyma cells to tracheids, are closely related to substances, and/or their precursors, formed in the heartwood.

Specific gravity

In the present study the wood of *Cryptomeria japonica* D. Don sampled from Shanping shows very high specific gravity as compared with others that have been reported elsewhere (Wang and Lin., 1994). The average specific gravities based on oven dried weight and volume were 0.66 and 0.56 for tree I and tree II, respectively

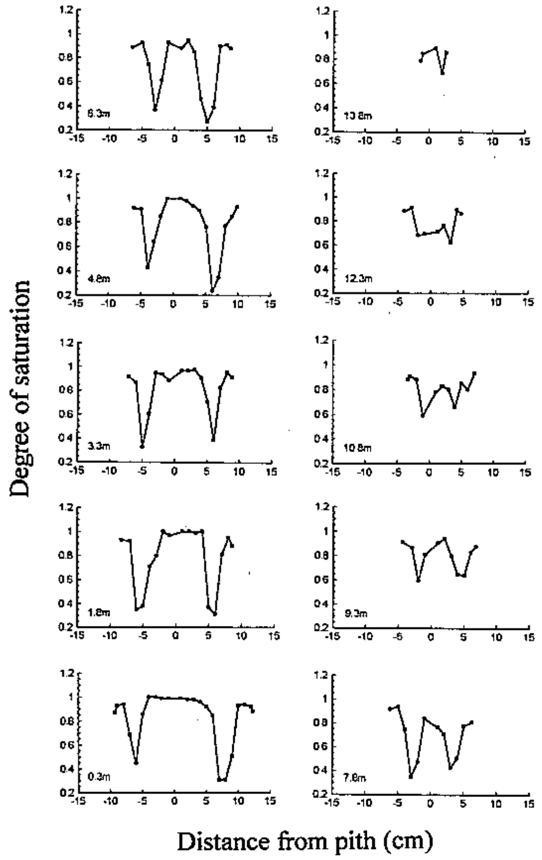

Fig. 4. Radial variation of degree of saturation (Tree I).

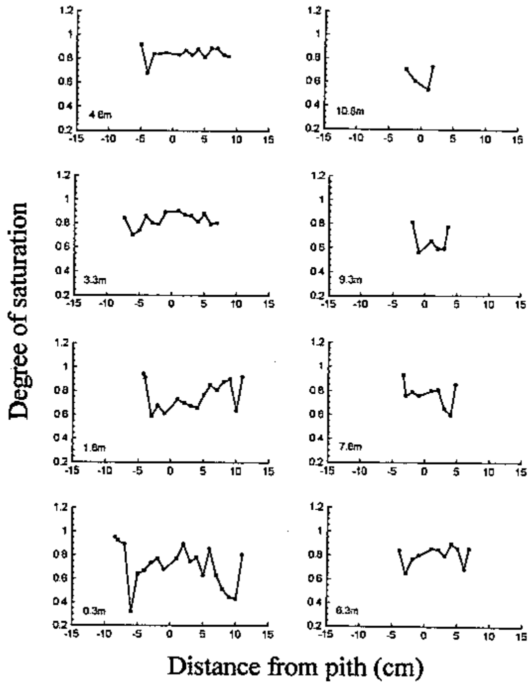

Fig. 5. Radial variation of degree of saturation (Tree II).

(Table 3). They varied from 0.37 to 0.76 as shown in Fig. 2. However, it has been reported by Chang *et al.* (1997) that the specific gravity ranged from 0.352 to 0.488 for non-dominant and dominant trees. The diameters of the sample trees were apparently much smaller than those sampled from other regions. As stated by Haygreen and Bowyer (1984), softwoods with prominent latewood has a density tending to decrease slightly as the growth rate increases.

The specific gravity of a growing tree is affected by site-related factors, such as moisture, availability of sunlight and nutrients, wind, and temperature. It is also influenced to a large extent by elevation, aspect, slope, latitude, soil type, stand composition, and spacing. All these factors can affect the size and wall thickness of cells and thus the density. However, species differ greatly in their sensitivities to site factors (Haygreen and Bowyer, 1982). Many factors of site, climate, geographic location, and species affect the specific gravity of wood. Since many of these occur in combination, it is difficult to separate the independent effects. There is a great deal of scientific literature dealing with these rela-tionships, the inconsistencies of which indicate the complex interactions among these factors. Just as Wang and Lin (1984) have mentioned, there is no fixed data for the specific gravity for any tree.

Generally speaking, the results in this study show that the specific gravity of the wood of *Cryptomeria japonica* D. Don increases very slightly from the ground upward (Fig. 12). And the specific gravity of the heartwood is generally higher than that of sapwood due to the higher percentage of extractive content. In Figs. 13 and 14, it can be seen that both the specific gravities of the sapwood and heartwood increase from the ground with a maximum at a tree height around 8 m.

Since most wood moisture exists in cell cavities of green wood, a negative correlation between specific gravity and moisture content was obtained (Fig. 9). It also can be seen in Figs. 2 and 3 except in the dry zone area. Chang *et al.* (1997) have the same result in the green wood of

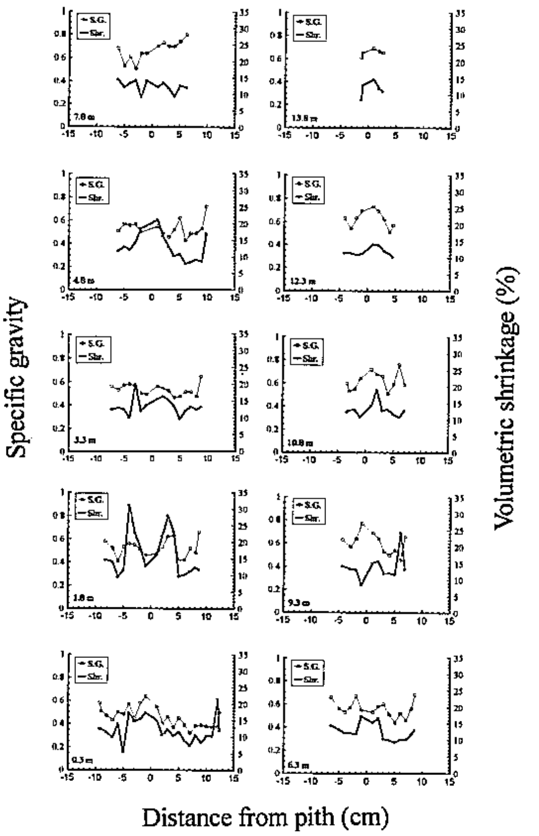

Fig. 6. Radial variations of specific gravity and volumetric shrinkage (Shr.) in Tree I.

Japanese cedar and China fir. The result can be explained by the fact that the higher the specific gravity, the more wood substances occupy the wood, so that there is less space for moisture to be replaced.

The radial variation of specific gravity in different heights of the tree trunk fluctuates and therefore reveals more complex patterns. The statistical analysis (Table 4) of radial variation shows that the specific gravity of heartwood is larger than that of sapwood, and that of the outermost block of each disk is apparently much larger than that of the rest. There is no significant difference between intermediate-wood and heartwood. In general, wood density (as indicated by specific gravity in this study) is dominated by the percentage of late-wood in a growth ring which is influenced by climatic and other complex ecological variables. In this study, the higher specific

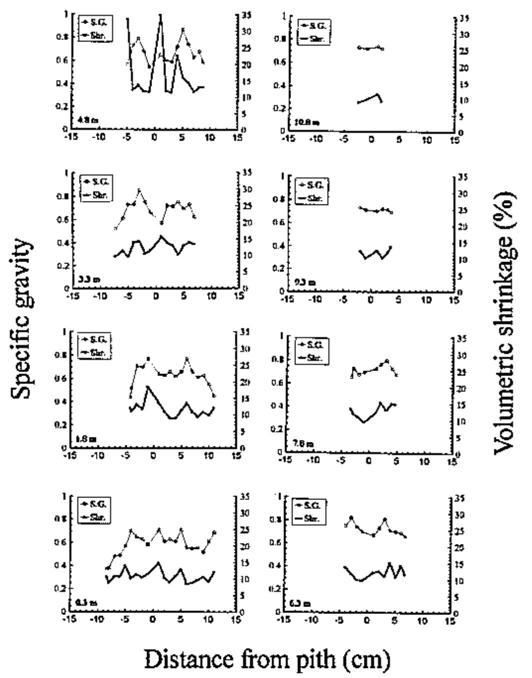

Fig. 7. Radial variations of specific gravity and volumetric shrinkage in Tree II.

gravity in the outermost blocks is caused by a larger number of growth rings as well as a high percentage of late-wood. The density of heartwood is more complex and depends on its chemical composition.

Volumetric shrinkage

The percentages of volumetric shrinkage from green to oven-dried wood have a positive correlation with specific gravity (Fig. 8). As in Figs. 6 and 7, similar patterns of radial variations of volumetric shrinkage and specific gravity are found in most of the disks investigated. However, since there is no significant correlation between tree height and specific gravity as mentioned above, the percentage of volumetric shrinkage therefore shows no significant correlation with the tree height as indicated in Fig. 8. Choong (1969) mentioned that the correlation would be improved when heartwood was extracted by hot water and/or organic solvent, since water does not enter the highly crystalline parts of the cellulose fibrils but instead moves into less ordered parts of the cell walls. It is generally believed that wood of high hemicellulose content will shrink more than that

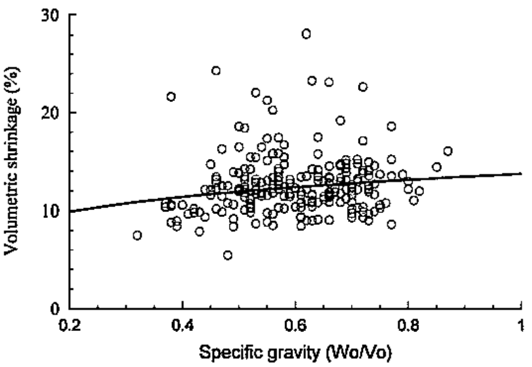

Fig. 8. Relationship between specific gravity and volumetric shrinkage.

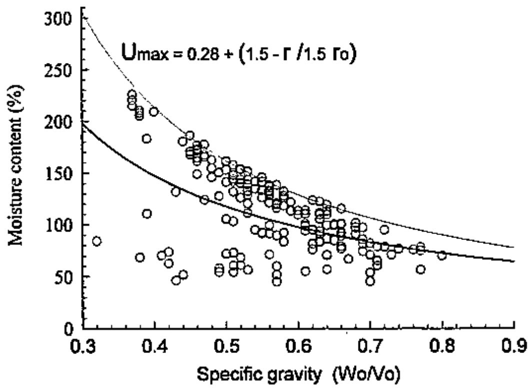

Fig. 9. Relationship between specific gravity and moisture content.

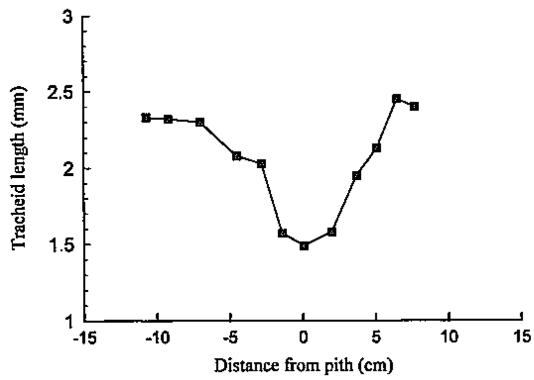

Fig. 10. Radial variation of tracheid length.

having a low level of hemicellulose. The chemical constituents of *Cryptermeria japonica* D. Don should therefore be further evaluated.

Growth rings and fiber lengths

As shown in Table 1, the number of growth

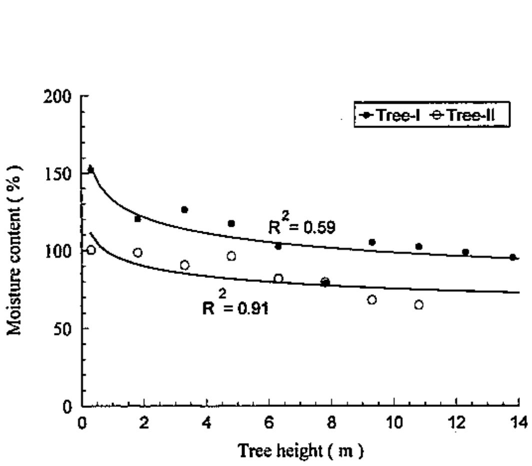

Fig. 11. Relationship between tree height and moisture content.

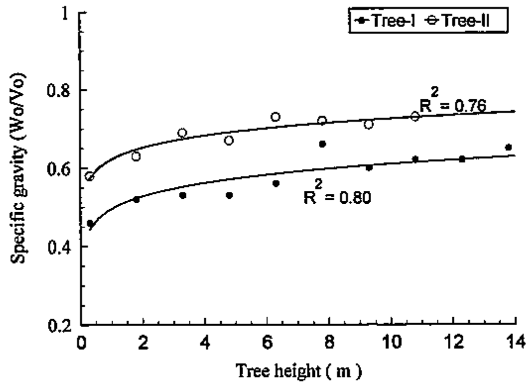

Fig. 12. Relationship between tree height and specific gravity.

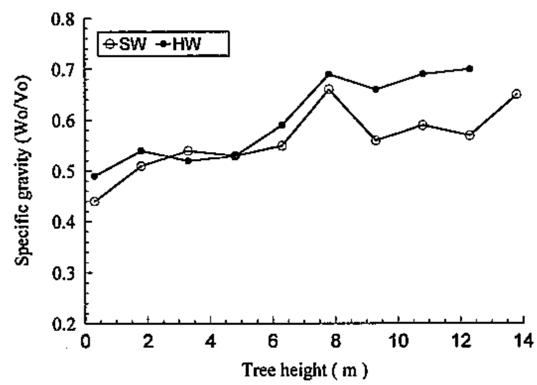

Fig. 13. Relationship between tree height and specific gravity of sapwood (SW) and heartwood (HW) in Tree I.

rings is apparently different between windward and leeward sides. Generally, the disks taken from the windward side possess a lower number

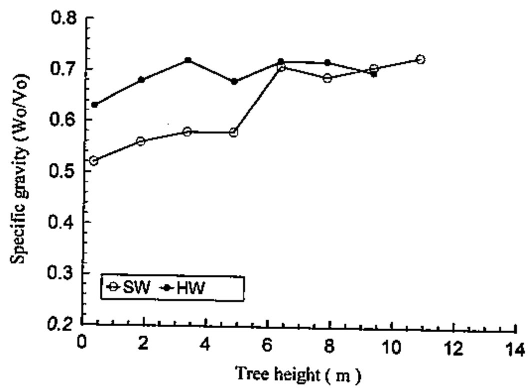

Fig. 14. Relationship between tree height and specific gravity of sapwood and heartwood in Tree II.

of growth rings. The fact can be explained by the nutrient flow and auxin supply from the crown. Furthermore, it is believed that nutrients as well as auxin take as long as 3 wk to reach the stump of a mature tree. Cambium may fail to function as the site for cell division when nutrients and auxin are exhausted before reaching the point, and thus the growth ring ceases to increase in that year. Therefore, one should be very careful when determining the age of a tree by counting the number of growth rings.

The maturation of wood can be shown by the constant length of tracheids (Chiu and Lee, 1996). It can be seen in Fig. 10 that tracheid lengths in disks at breast height around 1.3 m, increase from the pith outward to a maximum at growth ring 20, after which lengths remain almost constant thereafter. It is interesting that the widths of growth rings from this point to the bark also remain approximately constant. Therefore, the maturation of wood, which is about 25 yr of age shown in this study, is consistent with constant tracheid length and growth rings width. Others, e. g., Chang *et al.* (1997) also found that the length of tracheids increase with age.

The relationship between moisture content, specific gravity, and tree height

The vertical variations of moisture content, specific gravity, and volumetric shrinkage were analyzed by using the averaged data of the disks 0.3 m above the ground at 1.5-m intervals. In general, the results show that moisture content has a negative correlation with tree height (Fig. 11), while specific gravity increases from the ground upward (Fig. 12).

In Figs. 13 and 14, it can be seen that both the specific gravities of sapwood and heartwood increase from the ground to a maximum at a tree height around 6-8 m. On the other hand, the specific gravity of heartwood is higher than that of sapwood. This may be explained by the higher percentage of extractive content in heartwood.

CONCLUSIONS

The results show that moisture content in green wood of *Cryptomeria japonica* D. Don studied are distributed in 3 distinct areas. The relatively low moisture content of the dry zone is located in the intermediate area between the sapwood and heartwood. The moisture content of the wet area is rather high and even reaches its moisture saturation point in the heartwood. The degree of saturation in the dry zone is only 1/2 to 1/3 that of wet wood. The percentage of volumetric shrinkage correlates positively with specific gravity, while moisture content shows negative correlation with specific gravity. Tracheid lengths increase from the pith outward to a maximum during the maturation of the standing tree. The specific gravity of wood increases from the stump upward to the crown, while the moisture content has negative correlation with the height of the standing tree.

LITERATURE CITED

Chang, Y., B. Chen, and J. Chen. 1997. Evaluation of the tissue characteristics and mechanical properties of wood from man-made forest (I) The tissue characteristics and mechanical properties of Japanese cedar and China fir. J. Expt. For. NCHU. 19(1): 35-52. [in Chinese with English summary].

Chen, Y. S. 1992. The study on the inorganic cell inclusions and druse-like silica grains in the mature stems of *Calamus longisetus* Griff. Taiwan J. For. Sci. 7(2): 149-160. [in Chinese with English summary].

Chiu, C. M., and C. H. Lee. 1997. The validity of a new technique differentiating between juvenile and mature wood in conifers. Taiwan J. For. Sci. 12(4): 387-392.

Choong, E. T. 1969. Effect of extractives on shrinkage and other hygroscopic properties of ten southern pine woods. Wood Fiber 1: 124-133.

Cutts, M. P. 1976. The formation of dry zones in the sapwood of conifers. I. Induction of drying in standing trees and logs by *Fomes annosus* and extracts of infected wood. Eur. J. For. Path. 6: 372-381.

Cutts, M. P. 1977. The formation of dry zones in the sapwood of conifers. II. The role of living cells in the release of water. Eur. J. For. Path. 7: 6-12.

Cutts, M. P., and J. Rishbeth. 1977. The formation of wetwood in grand fir. Eur. J. For. Path. 7: 13-22.

Ewers, F. W. 1985. Xylem structure and water conduction in conifer trees, dicot trees, and lianas. IAWA Bull. N.S. 6(4): 309-317.

Fujii, T., Y. Suzuki, and N. Kuroda. 1997. Bordered pit aspiration in the wood of *Cryptomeria japonica* in relation to air permeability. IAWA J. 18(1): 69-76.

Haygreen, J. G., and J. L. Bowyer. 1982. Forest products and wood science, an introduction. The Iowa State University Press, USA. pp. 204-217.

Hillis, W. E. 1987. Heartwood and tree exudates. Springer-Verlag, Berlin, Heidelberg.

Nobuchi, T., and H. Harada. 1985. Ultra-structural changes in parenchyma cells of Sugi (*Cryptomeria japonica* D. Don) associated with heartwood formation. Mokuzai Gakkaishi 31(12): 965-973.

Panshin, A. J., and C. de Zeeuw. 1980. Textbook of wood technology. 4th ed. McGraw-Hill Book Company, New York, USA. pp. 212-214.

Sperry, J. S. 1985. Xylem embolism in the palm *Rhapis excelsa*. IAWA Bull. N.S. 6(4): 283-293.

Takahachi, K. 1996. Relationships between the blacking phenomenon and norlignans of Sugi. Mokuzai Gakkaishi 42(10): 998-1005.

Torelli, N., K. Cufar, and D. Robic. 1986. Some wood anatomical, physiological, and silvicultural aspects of silver fir dieback in Slovenia (NW Yugoslavia). IAWA Bull. N.S. 7(4): 343-350.

Wang, S., and T. Tin. 1984. Wood products. Commercial Press, Taiwan, ROC. pp. 153. [in Chinese].

Wang, S., and F. Lin. 1994. Effects of plantation spacing on density, and mechanical properties of Japanese cedar grown in Taiwan. NTU Agri. Res. Pap. 34(2): 124-152. [in Chinese with English summary].