목재공학19(3) : 7~18(原著)
Mokchae Konghak.19(3) : 7~18. 1991

An Anatomical Research on Liquid-Penetration and Penetration-Path of Wood*1

Yu Jung Kim*2·Sang Jin Park*2

木材의 液體浸透性과 浸透經路에 關한 組織學的 硏究*1

金柔姃*2·朴相珍*2

摘 要

木材의 液體浸透性을 硏究하기 위하여 國內에 있는 針葉樹材와 闊葉樹材의 主要樹種을 대상으로 軸方向, 放射方向, 接線方向의 浸透를 각각 調査하였다. 또한 放射 및 接線方向의 主要 浸透經路를 光學顯微鏡으로 觀察하였다.

實驗結果는 다음과 같다.

1. 縱浸透는 針·闊葉樹材 모두 1% NH_4OH 處理시 浸透性이 가장 컸으며 樹種에 따른 浸透性의 差異는 針葉樹材인 잣나무가 闊葉樹材인 물푸레나무와 현사시나무 보다는 더 컸으며 闊葉樹材內에서는 물푸레나무가 현사시나무보다 浸透性이 더 큰 것으로 나타났다.

2. 橫浸透는 針葉樹材에 있어서 浸透面別 浸透量은 接線斷面이 放射斷面보다 훨씬 컸으며, 闊葉樹材의 경우는 環孔材에서는 接線斷面이 放射斷面보다 浸透量이 컸으나, 散孔材에서는 樹種間의 變異가 컸다. 闊葉樹材의 環孔材와 散孔材 모두 放射組織이 橫浸透에 미치는 影響은 針葉樹材만큼 크지 않았다. 浸透깊이도 針葉樹材가 闊葉樹材보다 컸으며, 闊葉樹材는 樹種間의 差異가 심했다.

3. 浸透經路를 보면 針葉樹材는 放射柔細胞, 晩材部의 小假導管이 主導的인 역할을 하였으며, 闊葉樹材도 역시 放射組織을 통해서 浸透가 이루어지지만 樹種間에 放射組織의 浸透樣式과 浸透速度가 달랐다.

1. INTRODUCTION

Anatomical characteristics of wood, especially capillary structures are very important factors to determine its liquid penetration[6]. Main capillary structures consist of tracheids in softwoods and vessel elements in hardwoods. Also, wood fiber, ray cell, intercellular space involving resin canal, and pit membrane play a role in liquid-penetration of wood. Besides these elements, transient capillary formation due to the hygroscopic property of cell wall also should be considered[8]. Wood cells are not consistent in shapes, sizes and their arrangement. Many researchers found that pit closure of the tracheid wall in

*1. 接受 1991年 6月 3日 Received June 3, 1991.
*2. 경북대학교 농과대학 College of Agriculture, Kyungpook National University, Taegu 702-701, Korea.

softwoods and tylosis formation of the vessel lumen in hardwoods were main retarding factors in their liquid penetration[2]. In addition to the features of wood, treating reagents and time are also strongly related to the penetration.

This study was performed to elucidate microscopically the characteristics of liquid penetration in radial and tangential surfaces of major domestic softwoods and hardwoods. The difference of mode of penetration by species was also discussed by microscopic observation of ray cells which appeared to play an important role in transverse penetration.

2. EXPERIMENTAL METHOD

2.1 Materials

2.1.1 Penetration in the longitudinal direction

The species examined for the longitudinal direction are *Pinus koraiensis* Sieb. et Zucc. for softwoods, *Fraxinus rhynchophylla* Hance. of ring-porous, and *Populus alba×glandulosa* T. Lee. of diffuse-porous for hardwoods.

2.2.2 Penetration in the radial and tangential directions

The species examined for the radial and tangential directions are *Pinus densiflora* Sieb. et Zucc., *Pinus rigida* Mill., *Picea jezoensis* Carr. for softwoods, *Quercus acutissima* Carruth., *Ulmus davidiana var. japonica* Nakai. for ring-porous hardwoods, *Populus maximowiczii* Henry., *Populus euramericana* Moench., *Betula costata* Trautv., *Alnus japonica* Steud., *Prunus sargentii* Rehder., *Platanus orientalis* L., *Tilia amurensis* Rupr., for diffuse-porous hardwoods.

2.2 Experimental Procedures

2.2.1 Penetration in the longitudinal direction

Columnar specimen, a diameter of 2cm, a length of 15cm, was made from sapwood at breast height of *Pinus koraiensis, Fraxinus rhynchophylla, Populus alba×glandulosa*. Each specimen is boiled with 1% solution NaOH, UREA, $CuSO_4$ and NH_4OH for two hours respectively, and then left in aceton solution for 90minutes after washing with water. The oven-dried specimen is coated with paraffine entirely except for both cross sections, and subsequently wound with vinyl tape for preventing water leakage during the experiment, thus only both cross sections were exposed. (Fig. 1 and 2).

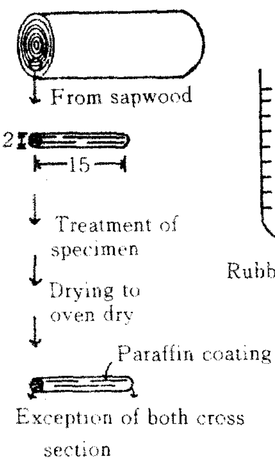

Fig.1. Order of specimen making.

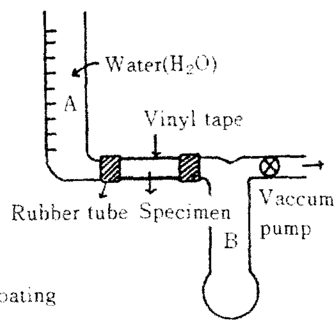

Fig. 2. Experimental equipment of water absorption in reduced pressure condition.

The watered specimen is placed between bottle A and bottle B and is connected with a rubber tube into a vaccum pump(Fig. 2). Then water is forced to penetrate for 100minutes with decompression condition of 1 atmospheric pressure or so(about 950-1,000mb).

The differences of characters and average rate of penetration by the treating reagents were compared.

2.2.2 Penetration in the radial and tangential directions.

The specimen for examining the radial and tangential directions were obtained by subdividing each specimen of 1×1×4cm(T×R×L).

The method used for liquid-penetration is as follows :

Air-dried specimen is coated with waterproof paints completely except for the penetrative section and is dipped in 1% solution of acidic Fuchsines in petridish. The changing weights of the specimen depending upon the rate of liquid-penetration were measured by a chmical balance with intervals ; 0.5, 1, 2, 4, 6, 8, 10, 11, 21 and 24hours.

After specimen is air-dried, thin sections (thickness : 30μm) were cut by a microtome. They are mounted by canada balsam, and permanent slides is prepared. The path and depth of penetration of each species is observed by light microscope.

3. RESULTS AND DISCUSSION

3.1 Penetration in the longitudinal direction

The amount of penetration of specimen treated with 1% NaOH in reduced pressure conditions is shown in Fig.3. The amount of penetration in *Pinus koraiensis* was twice as much as hardwoods for the first 20minutes. With increasing the penetrative time, the amount of penetration in *Pinus koraiensis* increased almost directly and rapidly. While

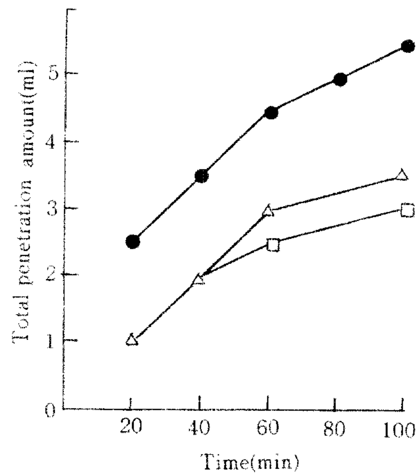

Fig.3. Comparision between species and total amount of penetration of wood treated with 1% NaOH.

Note : ● *Pinus koraiensis*

△ *Fraxinus rhynchophlla*

□ *Populus alba glandulosa*

the amount of penetration in *Fraxinus rhynchophyll* increased a little more than *Populus alba×glandulsa* for 60minutes, but its difference appears not to be large. Increasing tendency of amount of penetration in both species is not as large as *Pinus koraiensis*, and is on a parabolic increase.

The amount of penetration of specimen treated with 1% Urea in reduced pressure conditions is shown in Figure 4. The amount of penetration of *Pinus koraiensis* from 20minutes to 100minutes is much more than hardwoods. The total amount of penetration of *Pinus koraiensis* are over 10ml. *Fraxinus rhynchophyll* from 20 to 60 minutes is a little more than *Populus alba×glandulosa*. but become similar trends there after.

The amount of Penetration of specimen treated with 1% $CuSO_4$ in reduced pressure conditions is shown in Figure 5. When compared

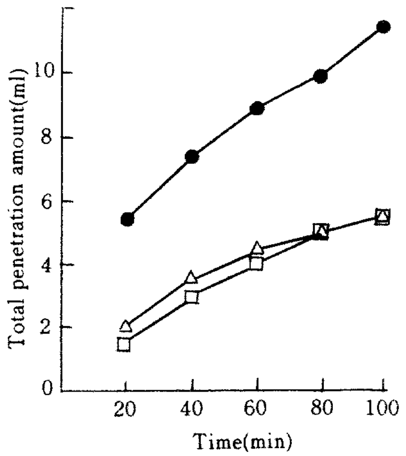

Fig.4. Comparision between species and total amount of penetration of wood treated with 1% UREA

Note : See symbols in Fig. 3.

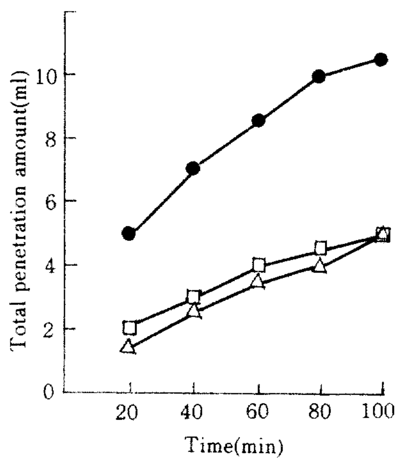

Fig.5. Comparision between species and total amount of penetration of wood treated with 1% $CuSO_4$

Note : See symbols in Fig. 3.

with Fig.4, the amount of penetration in 1% $CuSO_4$ is similar to 1% UREA but is a little lower only *Pinus Koraiensis* exceptionally than that in 1% UREA.

The amount of penetration of specimen treated with 1% NH_4OH in reduced pressure conditions is shown in Fig.6. *Pinus koraiensis* shows direct and rapid increase in the amount of penetration from 6ml for 20minutes to 13ml for 100minutes. Therefore it is the greatest in the both reagents treated and species. *Fraxinus rhynchophyll* and *Populus alba×glandulosa* have a little difference, as each 7ml, 6.5ml, but are the greatest among the other reagents.

This fact is closely related to the average rate of penetration(Table 1). As shown in Table 1, the average rate of penetration is the greatest when they are treated with 1% NH_4OH.

Also, in comparision of the amount of penetration among species, *Pinus koraiensis* of softwoods is greater than *Fraxinus rhynchophyll* and *Populus alba×glandulosa* of hardwoods. In hardwoods, *Fraxinus rhynchophyll* of ring-porous woods is some what larger than *Populus alba×glandulosa* of diffuse-porous woods.

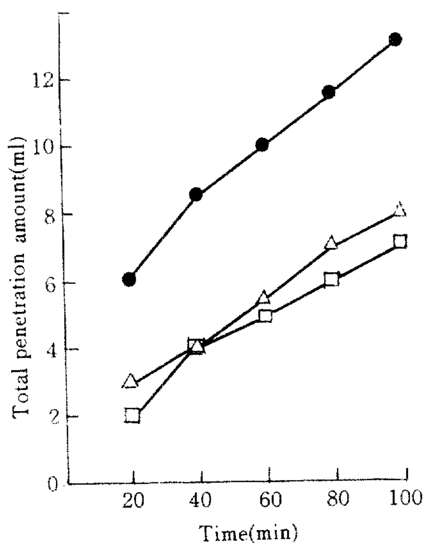

Fig.6. Comparision between species and total amount of penetration of wood treated with 1% NH_4OH

Note : See symbols in Fig. 3.

Table 1. Average penetration rate during 100minute according to treatment solution in *Pinus koraiensis*, *Fraxinus rhynchophylla* and *Populus alba x glandulosa*.

Species	Treatment solution	Average penetration rate(ml/Cm²,min)
	Nontreatment	0.000
	0.5% NaOH	0.018
	1% NaOH	0.024
	0.5% UREA	0.027
Pinus	1% UREA	0.041
koraiensis	0.5% $CuSO_4$	0.024
	1% $CuSO_4$	0.032
	0.5% NH_4OH	0.024
	1% NH_4OH	0.043
	Nontreatment	0.000
	0.5% NaOH	0.014
	1% NaOH	0.017
	0.5% UREA	0.025
Fraxinus	1% UREA	0.023
rhynchophyll	0.5% $CuSO_4$	0.013
	1% $CuSO_4$	0.023
	0.5% NH_4OH	0.017
	1% NH_4OH	0.032
	Nontreatment	0.000
	0.5% NaOH	0.012
	1% NaOH	0.014
Populus	0.5% UREA	0.015
alba x	1% UREA	0.024
glandulosa	0.5% $CuSO_4$	0.014
	1% $CuSO_4$	0.024
	0.5% NH_4OH	0.013
	1% NH_4OH	0.028

This results may be attributed to tracheids, which is efficient structure to move water in axial direction, consisting of 90 percentage of cells in softwoods[5]. In hardwoods, the reason why weighter *Fraxinus rhynchophylla* in specific gravity is greater than lighter *Populus alba*× *glandulosa* is that it has not check of water moving by vessels closure in the course of making heartwood, like tylosis because the specimen in only sapwood is extracted for the experiment[8].

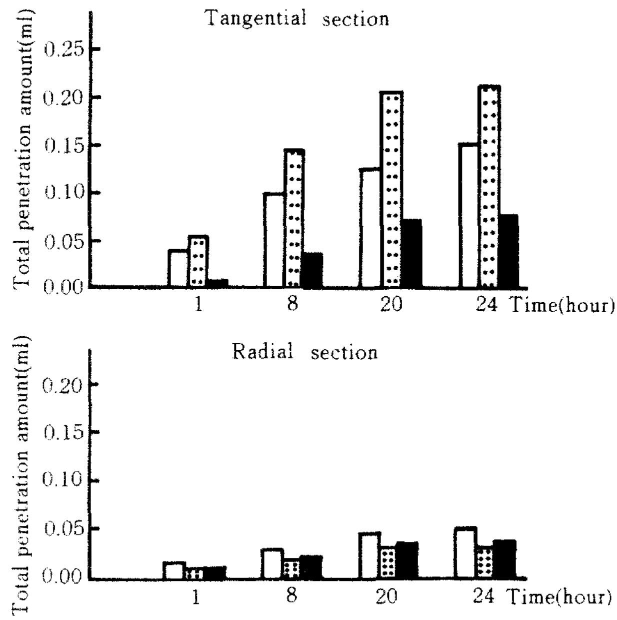

Fig. 7. Total penetration amount and variation between radial and tangential section during 24 hour in softwood.

□ *pinus densiflora* ; ⊞ *Picea jezoensis* ■ *pinus rigida*

3.2 Penctration in the radial and tangential directions

3.2.1 The amount and depth of penetration according to penetrative section

The amount of penetration according to penetrative section in softwoods is shown in Fig.7. The amount of penetration in tangential section is much larger than that in radial section. This result may be caused by rays playing roles as capillary tube in tangential section.

Also, the difference among species in radial section may reflect on penetration being closely related to size of cross-field pitting, *Pinus densiflora* in window like pit. *Pinus rigida* in pinoid pit, and *Picea jezoensis* in piceoid pit.

The amount of penetration according to penetrative section in ring-porous of hard-

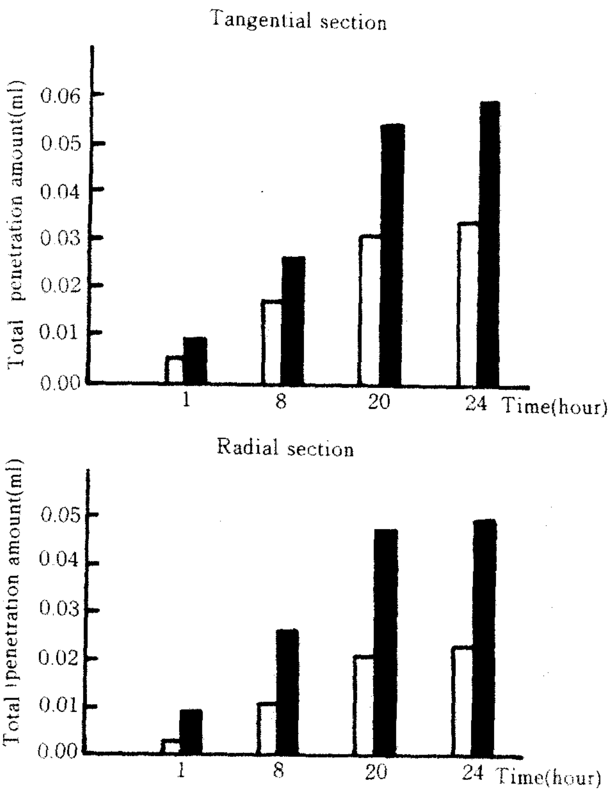

Fig. 8. Total penetration amount and variation between radial and tangential section during 24 hour in ring-porous wood.

□ *Quercus acutissima* ■ *Ulmus davidiana var. japonica*

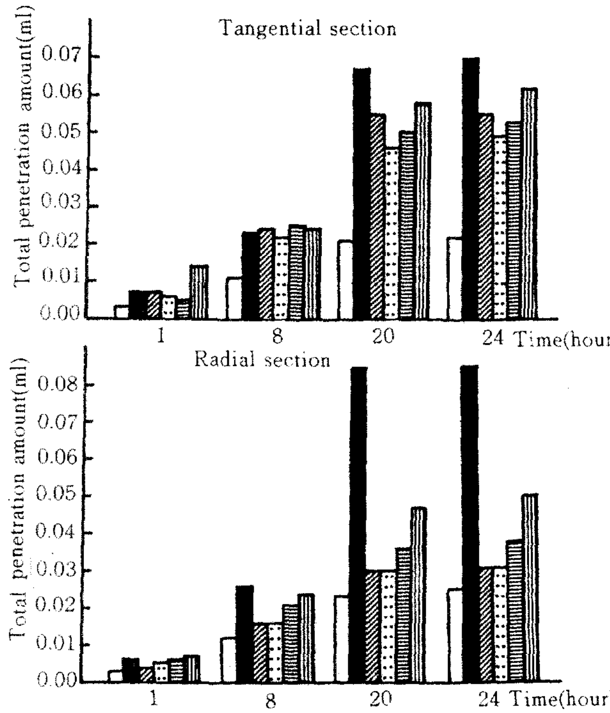

Fig. 9. Total penetration amount and variation between radial and tangential section during 24 hour in diffuse porous wood.

□ *Prunus sargentii* ▨ *Populus maximowiczii* ▤ *Alnus japonioa*
■ *Populus euramerioana* ⊡ *Betula costata* ▥ *Platanus orientalis*

woods is shown in Figure 8. The amount of penetration of tangential section in all two species is larger than that of radial section, but its difference is much smaller than in softwoods.

The amount of penetration according to penetrative section of diffuse-porous in hardwoods is shown in Fig.9. The amount of penetration of tangential section in *Prunus sargentii, Populus euramericana* is larger than that of radial section, and the amount of penetation of radial section in diffuse-porous except *Prunus sargentii* and *Populus euramericana* is larger than that of tangentialsection. But the difference according to section appears to be little.

Table 2. Penetration depth by radial and tangential section.

Species	Penetration surface	Penetration depth (mm)	Species	Penetration surface	Penetration depth (mm)
Pinus	R[1]	8.600	*Populus*	R	0.008
densiflora	T[2]	16.000	*euramericana*	T	0.012
Pinus	R	2.800	*Betula*	R	1.000
rigida	T	23.800	*costata*	T	1.200
Picea	R	3.800	*Alnus*	R	1.800
jezoensis	T	15.000	*japonica*	T	0.008
Quercus	R	0.005	*Prunus*	R	0.200
acutissima	T	1.600	*sargentii*	T	0.014
Ulmus davidiana	R	2.400	*Platanus*	R	5.600
var. japonica	T	4.000	*orientalis*	T	1.600
Populus	R	0.400	*Tilia*	R	2.400
maximowiczii	T	0.060	*amurensis*	T	3.800

[1]R : Radial section, [2]T : Tangential section

Especially, the amount of penetration of *Populus euramericana* is the largest in the hardwoods. But the cause of this is not evident.

Results measured about the depth of penetration in softwoods and hardwoods are shown Table 2.

The depths of penetration in both the radial and tangential section of softwoods are deeper than those of hardwoods. Particularly, while the depth of penetration of tangential section of *Pinus rigida* in softwoods is 23.3mm, that of radial section of *Quercus acutissima* in hardwoods is 0.005mm. The depth of penetration of tangential section is deeper than that of radial section in softwoods.

And, the depth of penetration of tangential section is deeper than that of radial section in the ring-porous. But the diffuse-porous is not found consistent tendency, and the difference of depth of penetration according to species and sections appears to be large.

Also, the above tendency of softwoods and hardwoods consist with the amount of penetration, but in the case of *Populus euramericana* exceptionally, while the amount of penetration is the largest in hardwoods investigated, the depth of penetration is the shallowest. This inconsistency is more surely investigated after observing the path of penetration.

3.2.2 The path of penetration

In softwoods, ray parenchyma and narrow tracheids of latewood appear to play the leading roles in penetration. In hardwoods, the radial and tangential penetration may be performed by rays, but the pattern and rate of penetration of ray among species are variable.

Fig.10. a, b show the path of radial and tangential penetration of *Pinus densiflora*. Comparing earlywood with latewood, we can observe that penetration through small bordered pits close to latewood tracheids is performed faster than it through wide bordered pits of earlywood(Fig. 10a). It is estimated that this phenomenon may result from capillarity(Fig. 11a). Also, we can see that rays play a leading role in the radial and tangential penetration, but penetration between rays and tracheids is not performed consistently-(Fig. 10b).

Fig.11. a, b show the path of radial and tangential penetration of *Pinus rigida*. We can also see that penetration through narrow tracheids of latewood is faster performed(Fig. 11a). Though penetration is performed faster through ray(Fig. 10b and 11b), we can observe that penetration into tracheids through ray is rather consistently performed in *Pinus rigida* than in *Pinus densiflora*. Especially, we should see noticeably, It is observed obviously in Fig.11. a that penetration of ray parenchyma is faster performed than ray tracheid. Buro, et al.[1] in Scotch Pine, and Erickson, et al.[3] in Douglas-Fir reported that penetration into radial direction is mainly dependent on ray tracheid, ray parenchyma is useful as a pathway or nearly non-penetration. On the contrary, Wardrop, et al.[7] described that ray parenchyma is penetrated better than ray tracheid. Also, Hayashi[8] reported that a distinct difference of penetration between ray tracheid and ray parenchyma was not confirmed. But in this experiment, it is observed that ray parenchyma played a leading role of penetration in *Pinus rigida*(Fig. 11a).

Fig.12. a, b show the path of radial and tangential penetration of *Alnus japonica*. In this

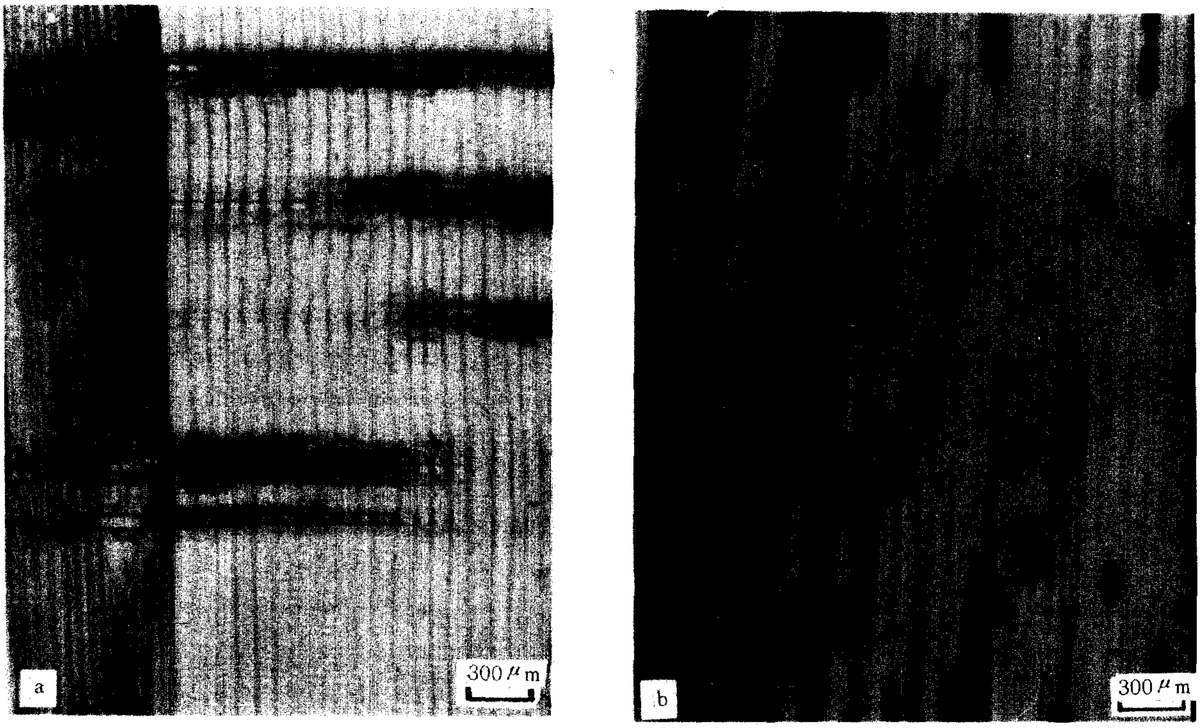

Fig. 10. Transverse-penetration of *Pinus densiflora* treated with the acidic fuchsins.

a : Penetration surface-R Observed section-R b : Penetration surface-R Observed section-T

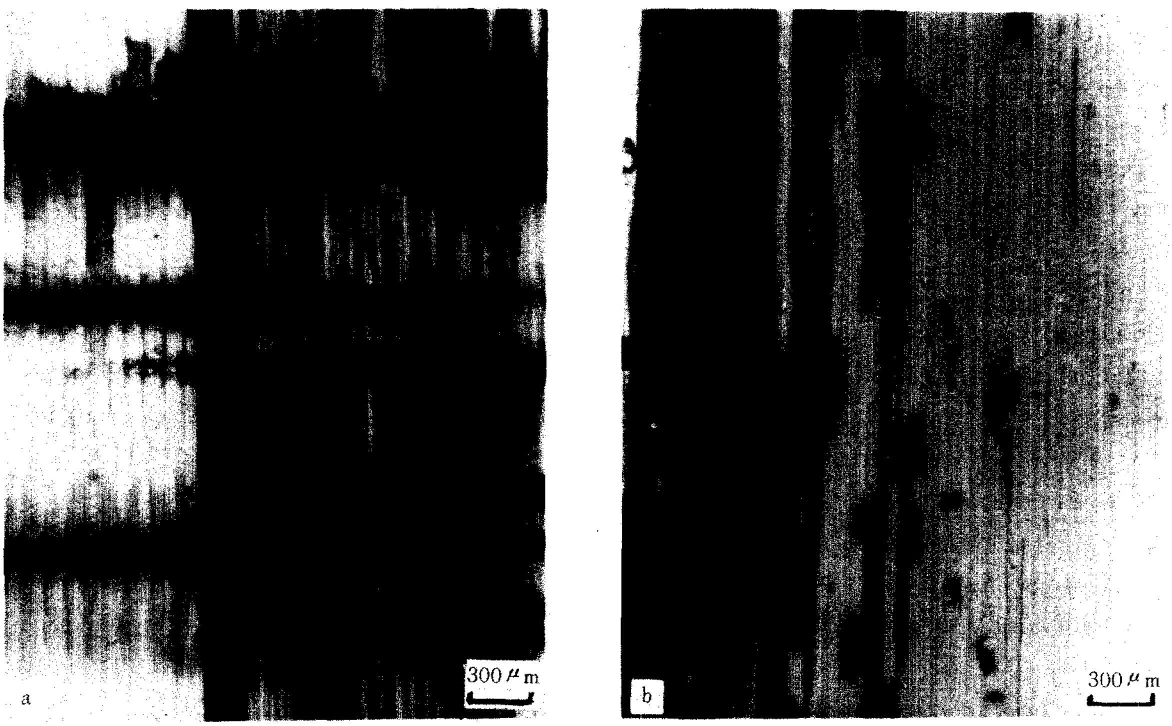

Fig. 11. Transverse-penetration of *Pinus rigida* treated with the acidic fuchsins.

a : Penetration surface-T Observed section-R b : Penetration surface-R Observed section-T

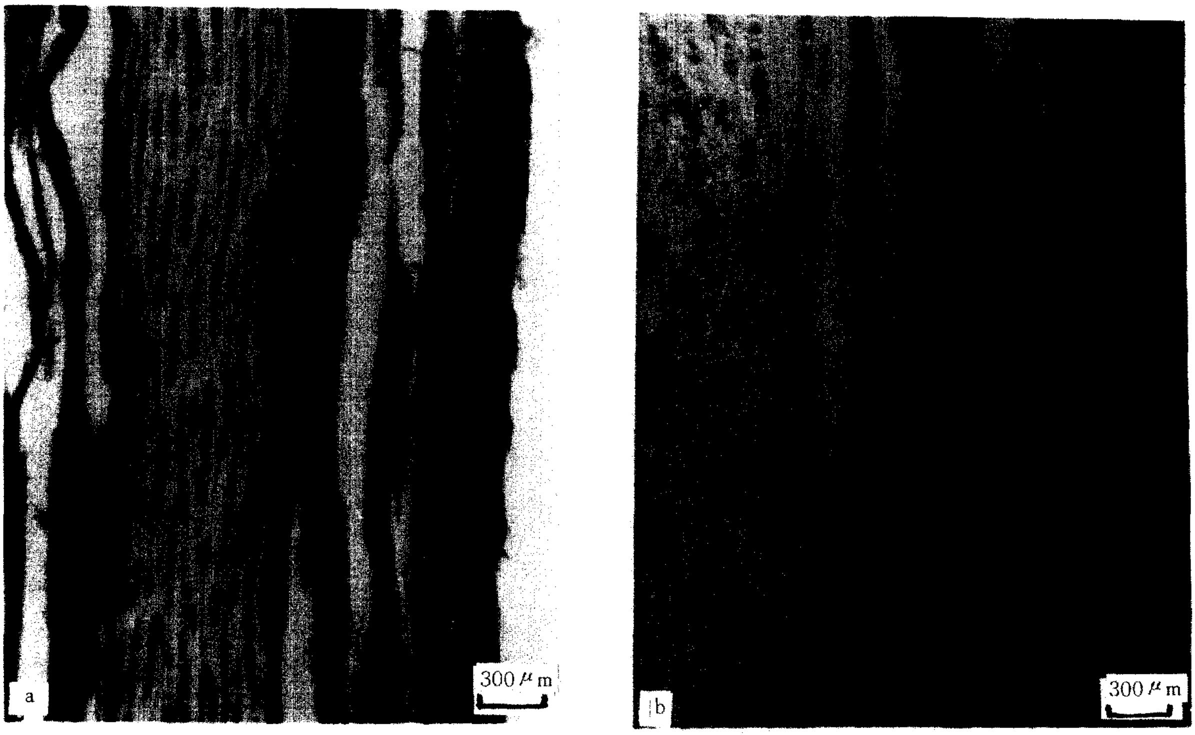

Fig. 12. Transverse-penetration of *Alnus japonioa* treated with the acidic fuchsine.

a : Penetration surface-R Observed section-T b : Penetration surface-T Observed section-R

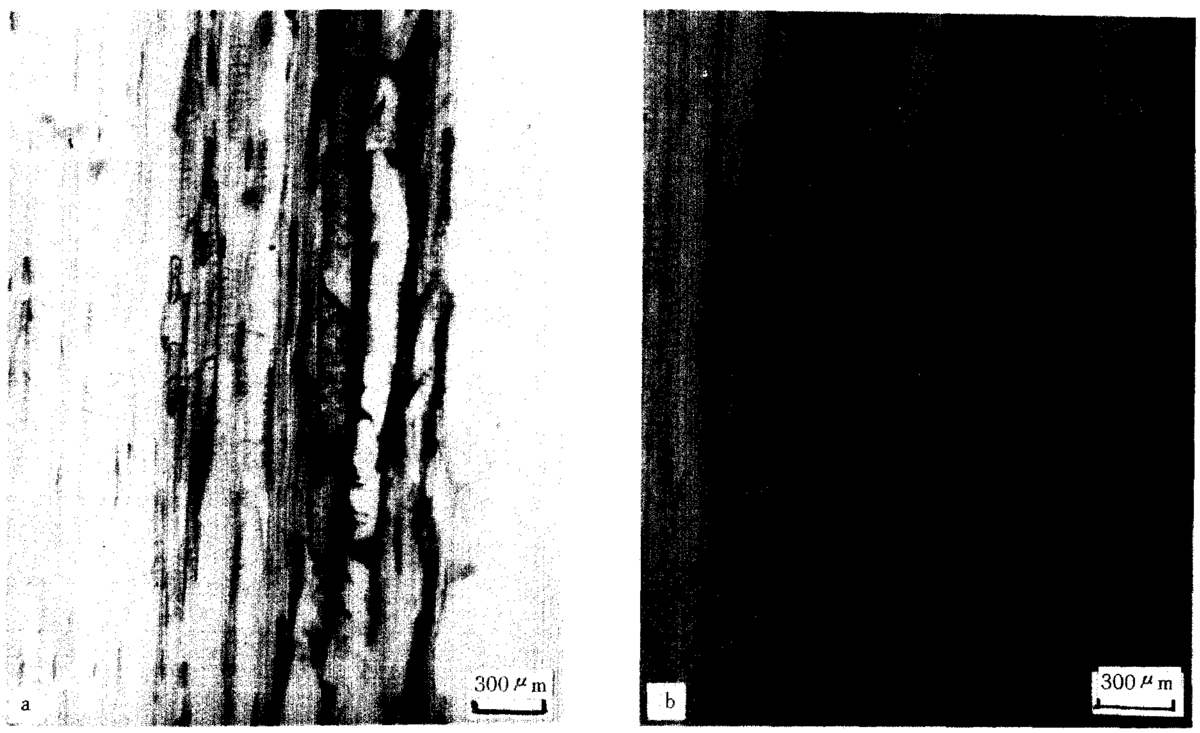

Fig. 13. Transverse-penetration of *Populus maximowiczii* treated with the acidic fuchsins.

a : Penetration surface-T Observed section-R surface-R Observed section-T b : Penetration

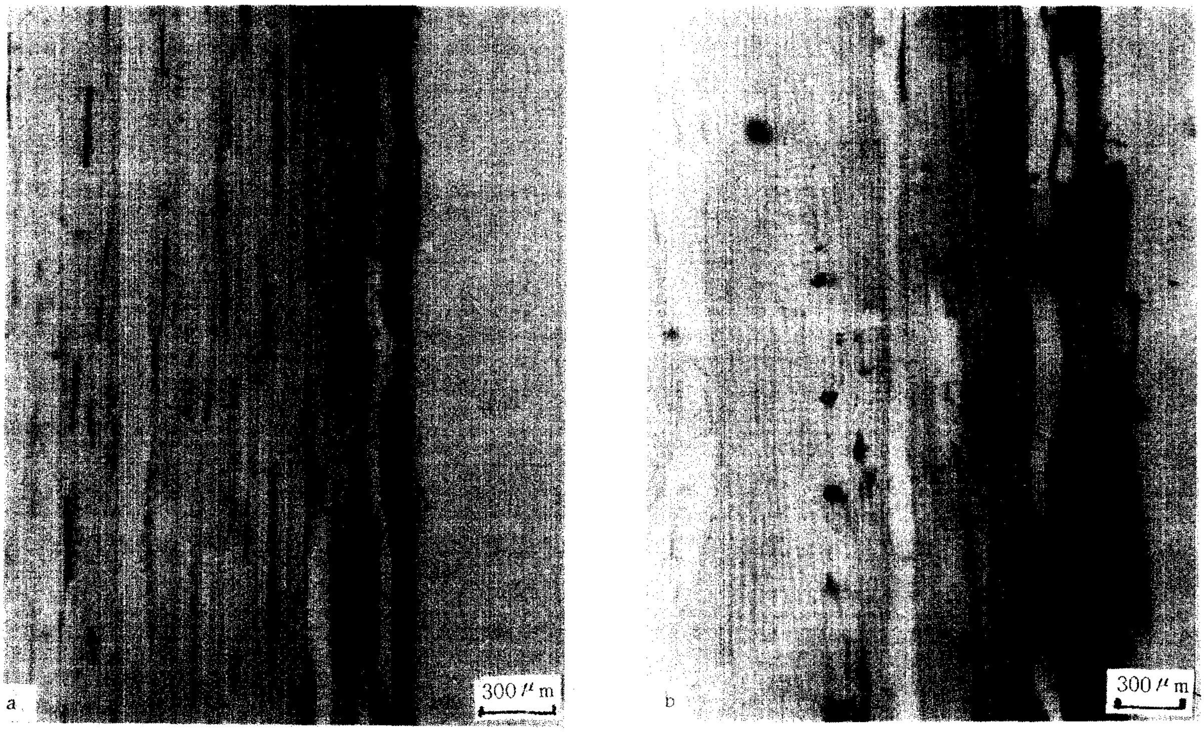

Fig. 14. Transverse-penetration of *Populus eur americana* treated with the acidic fuchsins.

a : Penetration surface-R Observed section-T b : Penetration surface-T Observed section-R

Fig. 15. Transverse-penetration of *Prunus sargentill* and *Platanus orientalis* treated

a : *Prunus sargentii* Penetration surface-R Observed section-T b : *Platanus orientalis* Penetration surface-R Observed section-T species penetration through ray is first performed, then penetration between ray and wood fiber subsequently. Especially, though this species have aggregate ray(Fig. 12a, b), penetration is performed through prefering uniseriate ray to aggregate ray, later into wood fiber, but aggregate ray is not nearly penetrated.

Fig.13. a, b show the path of radial and tangential penetration of *Populus maximowiczii*. Where penetrative section is radial section, the rate of penetration of ray is more or less faster than wood fiber. But in the case of tangential section, though penetration among rays is not performed consistently, the rate of penetration of ray is very fast.

Fig.14. a, b show the path of radial and tangential penetration of *Populus euramericana*. The rate of penetration is very slow in both the radial and tangential section. Though penetration is performed through ray in both sections, the difference of rate of penetration between wood fiber and ray is not confirmed.

Fig.15. show the path of radial and tangential penetration of *Prunus sargentii* and *Platanus orientalis*. In the above two species-(Fig. 15) a strange phenomenon is found. A leading role of radial and tangential penetration of all species is performed by ray, whereas only in *Prunus sargentii* and *Platanus orientalis*, penetration of both the radial and tangential section is first performed by not ray but wood fiber. We think that multi-sided investigation ought to be needed afterward because any mechanism can not be explained from mere results of this experiment.

From the path of penetration of softwoods and hardwoods observed above, Examining relationship among the rate of penetration of ray, the amount of penetration and the depth of penetration, we can see the following next. In softwoods, the rate of penetration of ray is much faster than hardwoods. This is the same in comparision of the depth of penetration, too. Also, as softwoods is simpler than hardwoods in cell composition, the amount of penetration increased in proportion to the rate of penetration of ray.

on the other hand, in hardwoods, the rate of penetration of ray among species is variable and is not performed consistently between radial and tangential section because cell composition of hardwoods is very complicated. For example, while the rate of penetration of ray of *Populus euramericana* in both the radial and tangential section is very slow, the amount of penetration is the greatest. In the characteristics of radial and tangential penetration of this species, we can see that ray plays a leading role of radial and tangential penetration, but a larger amount of penetration is performed through cells like wood fiber or vessels and so on, except ray. On the contrary, while the rate of penetration of ray of *Populus maximowiczii* in tangential section is the fastest when is compared with other species, the amount of penetration is only a little because penetration through other cells, like wood fiber or vessels and so on, is a little. Therefore, the rate of penetration of ray dose not consists with the amount of penetration.

In conclusion, though penetration through ray appears to be first performed in hardwoods which has various cell composition, the penetration through other cells may play an important role in the amount of penetration.

4. CONCLUSION

The results of experiment was as follows :

1. Penetration in the longitudinal direction, 1% NH_4OH was the most effective in penetration, regardless of softwoods and hardwoods. Generally the rate of penetration of softwoods was higher than that of hardwoods. In hardwoods, ***Fraxinus rhynchophylla*** was higher than ***Populus alba×glandulosa*** in liquid-penetration.
2. Penetration in the radial and tangential directions, tangential penetration was higher than radial penetration in softwoods. In the case of hardwoods, the rate of penetration of ring-porous wood was similar to that of softwoods but that of diffuse-porous wood showed significant deviation among species. Also the depth of penetration of softwoods was deeper than that of hardwoods.
3. Concerning the path of penetration, ray parenchyma and narrow latewood tracheid of softwoods and ray cell of hardwoods appeared to play a leading role but the mode and rate of penetration were varied from the species.

LITERATURE CITED

1. Buro, A. and E.A. Buro. 1959. Holzforschung, 13 : 71.
2. Cote, W.A. JR. 1963. Structal factors affecting the permeability of wood. J. of Polymer Sci, 2 : 231-242.
3. Erickson, H.D. and J.J. Baratinecz. 1962. Forest Prod. J., 14 : 293.
4. Hayashi, H. 1968. The anatomical research on liquid-penetration of wood. Kyoto university. Thesis of Doctor's degree, P. 1-62.
5. Jung, H.S. 1990. "Wood seasoning". Sun Jin Co, p. 62-64.
6. Park, S.J., W.Y.Lee. and H.Y.Lee. 1987. "Wood anatomy and identification. Hyang Moon Co, p. 95., 36.
7. Wardrop, A.B. and Davies, G.W. 1961. Holzforschung, 15 : 129.
8. Wee, H. 1985. Wood Physics. Hyang Moon Co, p. 106., 119., 120.