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Lateral Penetration of Water in Ray Parenchyma Cells of *Castanea crenata*[1]

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ABSTRACT

This experiment states the ultra pure distilled water penetration depth through ray parenchyma cell in radial direction of *Castanea crenata*. Heartwood penetration depth was 1.16 times lower than the depth in softwood and that difference was found statistically significant at 75.2 second of penetration. Following go-stop-go cycle, water penetrated in the ray parenchyma cell. At the beginning this speed was high and then it was decreased slowly. Water penetration depth result was compared with alcohol penetration depth. It was found that water penetration in ray parenchyma was found lower than alcohol due to the low surface tension of water.

Key words: Water penetration, radial penetration, capillary rise, surface tension.

INTRODUCTION

Wood is material used in many building and construction applications. Unfortunately, wood degrades biologically if certain condition (e.g. the supply of water, oxygen and nourishment and a suitable temperature range) are met (Richardson 1993). Impregnation of wood has been widely used successfully for many years using different methods for wood products. One of the most important aspects of wood as far as impregnation is concerned what is related to its porosity and how internal cavity at a microscopic level communicates each other. Although much effort has been put trying to understand liquid flow in wood and more importantly the factors that limit liquid flow in wood and many questions remain unanswered. Variations in the morphology of the interconnecting pits within and among species add to the complexity of being able to predict reliably the success of a particular treatment with different liquids. Different techniques and methods so far have been developed to obtain quantitative and qualitative information about liquid penetration (Rudman 1965) though the amount of liquid penetration is different for sapwood and heartwood. The solution uptake by cells is affected by wettablility of the surface of the cell lumen (Iida et al. 2002). Factors of prime consideration governing the flow are the amount of pressure, etc. Siau (1995) reported that multiseriate rays are low permeable and bring down the permeability. He also stated that in hardwood for unknown reasons, conduction through ray tissue is not nearly as important, despite the grater abundance of rays. Even though the heterogeneous structure of hardwood and low importance in radial penetration, we investigated the ray cell role and penetration depth of water in *Castanea crenata*. This experiment will help us to know the radial conduction of water for this

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species. We also explained the reason for which radial penetration depth was differed from liquid to liquid using same wood species in same moisture content.

MATERIALS AND METHODS

Sample preparation and penetration depth measurement

Wood samples of *Castanea crenata* Sieb. et Zucc. were obtained from Jiamri, Sabukmeyon, Chunchon, Kangwon-do, Republic of Korea. Immediately after sample collection from defect free tree, discs were made and marked to identify top and bottom end. Penetration was allowed from bark to pith direction. Sample of 4 cm (longitudinal) x 1 cm (radial) x 0.5 cm (tangential) were prepared after microtome shaving. Except one radial and tangential surface, all surfaces were coated with silicon resin for preventing the leakage by other surfaces. Liquid penetration measurement was done by following the same methodology mentioned by Ahmed et al. (2007).

Considered liquid

Ultra pure distilled water was used for measuring liquid penetration depth. Ultra pure distilled water was collected from Water Purification System- Scholar, Next Power 1000. Its density was 0.9973g/cc and surface tension was measured to 71.88 dyne/cm at 24^0C.

Statistical analysis

The statistical analyses were done by using SPSS statistical package program (SPSS, Version 12.0.1, 2003). The analyses of variance for the characters under study were performed by two-sampled analysis (at alpha= 0.01 or 99% confidence level) to identify significant differences between treatments.

RESULTS AND DISCUSSION

Castanea crenata possessed exclusively uniseriate ray parenchyma. Procumbent ray cell diameter was 10.08 μm (SD= 3.15, range= 5.62~16.49 μm), procumbent ray cell length 55.66 μm (SD= 22.38, range= 16.51~120.48 μm) and endwall pit number of ray cell 17.07 (SD= 3.95, range= 12~5).

It is reported that moisture content of wood plays a vital role for the liquid impregnation. Browning (1963) stated that above the fiber saturation point until the cell cavity are filled with liquid water; wood can still up take water by absorption or capillary action. In addition, excess moisture in wood voids may also act as a physical barrier for the mass flow of liquid (Wirspa and Libby 1950). Moisture content of *Castanea crenata* was recorded 29.1% in sapwood and 27.9% in heartwood. In this moisture level, water penetration depth in ray cells is presented below.

Table 1. Water penetration depth in ray cells unit: μm

Type of wood	18.8 sec	37.6 sec	56.4 sec	75.2 sec
Sapwood	18.75	22.24	26.09	28.20
Heartwood	13.49	17.73	22.97	24.32
Level of significance	**	**	**	**

** Significant at 1 % level of probability

Water penetration depth increased significantly from heartwood to sapwood in radial direction, t(9)= 2.992, p= 0.015 measured at 75.2 second of penetration.

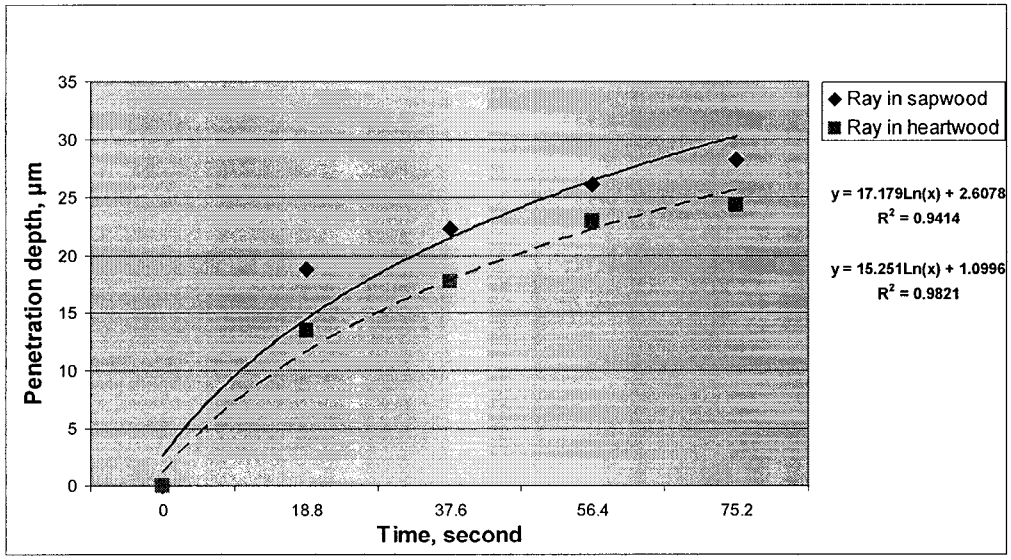

Fig.1. Line graph showing radial penetration of water through ray parenchyma cell.

Water penetration was in consequence of capillary flow, wetting, and diffusion. The rate of penetration was fastest at the beginning (18.8 second) and then slowly decreased in an uneven rate (Fig. 1). In radial direction, sapwood was 1.16 times more permeable than heartwood when measured at 75.2 second penetration. After 18.8 second of infiltration in radial direction, it decreased upto 81% at 37.6 second, 82% at 56.4 second and 93% at 75.2 second. Initial water infiltration speed was high and then the speed was decreased unevenly. By go-stop-go cycle, water penetrated through ray parenchyma cells until and unless the capillary pressure of water created by cell lumen is equal to pressure of air above the air-water interface. In this case, it seems to stop the infiltration. It is well known that liquid penetration depends upon the wood structure and liquid itself.

If a liquid has a contact angle θ with a thin capillary tube, it produces an associated vertical force on the liquid, the capillary force which is given by,

$F = 2\pi r\gamma Cos\theta$---------- (1)

If the wetting angle θ is less than 90^0, causes the fluid to rise in a thin capillary tube. While if the angle is greater than 90^0, the fluid in the capillary drops. The real reason for this effect is the surface energy between the fluid and the walls of the capillary. If this energy is favorable, the fluid wants to make more contact with the capillary surfaces, which induces the rise in the capillary tube. The height to which a fluid rises or falls is determined by a balance of the capillary force with the force of gravity,

$F = mg = \rho V g = \pi r^2 h\rho g$---------- (2)

Solving for h, we find that, $h = 2\gamma Cos\theta/ \rho gr$ where, m= mass of liquid in capillary (g), g= gravitational acceleration (980g/cm^2), ρ= density of liquid in the capillary (g/cm^3), V= volume of liquid in the capillary (cm^3), r= radius of capillary (cm), h= height of capillary rise (cm).

If the liquid has lower surface tension which make smaller contact angle with cell wall will penetrate deeper than the liquid which has higher surface tension and contact angle with cell wall.

Alcohol permeability depth in *Castanea crenata* was obtained by Lee et al. (2007). If we compare the water penetration results with those of alcohol, we will find that the alcohol penetration depth was higher than water. After 75.2 second, alcohol penetrated 120.14 μm in sapwood and 71.17 μm in heartwood through ray parenchymas (Lee et al. 2007). But in this experiment we found the water penetration depths through ray parenchymas were 28.20 μm for sapwood and 24.32 μm for heartwood. This result difference was for liquid properties. Alcohol has low surface tension, 20.35 dyne/cm at 24°C while 71.88 dyne/cm for water. Also contact angle or meniscus angle (Fig. 2) is also responsible for liquid permeability in wood. Lower meniscus angle ($\theta<90^{o}$) of water means the higher adhesion force with cell wall which leads water to more contact with cell wall and ultimately rise capillary height. The theory mentioned in this experiment give us clear idea about the capillary rise. As this was one of the series experiment,

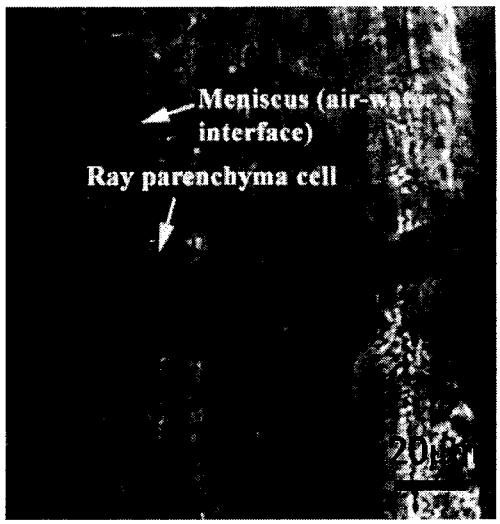

Fig.2. Meniscus in the ray parenchyma cell.

CONCLUSIONS

Ultra pure distilled water penetration depth in ray parenchyma was found high in sapwood than heartwood and the penetration depth was found 1.16 times higher measured at 75.2 second during penetration. This penetration depth difference was found statistically significant. At the beginning the penetration speed was high and then decreased in an uneven rate. Water penetration in ray parenchyma was found low for higher surface tension when it was compared with alcohol.

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