CHANGE OF TEMPERATURE AND PRESSURE IN DRY AND GREEN DOUGLAS-FIR AND SUGI WOOD DURING PASSIVE IMPREGNATION METHOD

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Abstract. This work investigated pressure and temperature change in green and dry Douglas-fir and sugi wood during passive impregnation treatment with copper azole type B preservative at higher concentration. Temperature and pressure sensors were used in wood for obtaining temperature and pressure change data every 10 s during the preservative treatment. Gross preservative and X-ray fluorescence spectroscopy was used to obtain retention. Penetration was measured following the standard. Although temperature rise was steeper in green Douglas-fir, pressure was higher in green sugi. However, phenomena were similar for dry lumber of both species. Preservative retention was very high (6.63 kg/m^3), and in most cases, it exceeded the requirements of permanent structural components in ground contact applications. Preservative penetration was almost 100% for all samples.

Keywords: Douglas-fir, passive impregnation, penetration, preservation, retention, sugi.

INTRODUCTION

Wood is an excellent renewable building material. However, when wood is used in ground contact or exposed to high moisture conditions, it may be subject to biological and insecticidal deterioration. To extend the service life of wood, especially in moist environmental conditions, it is important to impregnate preservative chemicals into wood.

Wood can be treated by different methods and chemicals. Because of current environmental concern, new preservatives and modified impregnation processes have been studied and developed, but still, release of suspected components occurs (Barnes and Murphy 1995). Alternative technologies such as the hydrothermolytical Plato process for low-quality wood upgrading (Ruyter and Hortulanus 1995; Pott et al 2000) and acetylation of wood are still introductory and are too expensive for most large-scale applications (Rowell et al 1986,

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1993; Suttie 1997). The recently developed passive impregnation method is as good as the best conventional method, ie full cell method (Islam et al 2007, 2009). In this new method, steam is injected into laser-incised lumber and then dipped into preservatives for a certain period of time. Steam carries heat into the wood through the incising holes and helps to expand air present in the cell lumens or evaporate moisture present in the wood, ensuring removal of air/water from cell lumens in dry/green wood. Steam also replaces air from cell lumens because of injecting force. All these processes increased the pressure. In dipping, the elevated temperature and pressure fall after preservative absorption by lumber. Hence, pressure and temperature inside the wood changes during steam injection and dipping, and pressure difference may lead to preservative absorption. However, there is no literature about changes of pressure and temperature inside wood during preservative treatment.

The objective of this study was to determine the relationship between temperature and pressure during steam injection and dipping for both green and dry lumber. Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and sugi (*Cryptomeria japonica* D. Don) were used in this study. The suitability of treating green and dry lumber by passive impregnation method with high preservative concentration was also studied.

MATERIALS AND METHODS

Both dry and green lumber of Douglas-fir (18 and 35% MC) and sugi (11 and 74% MC) were used. Square posts (108 × 108 mm) were cut to 650 mm long and used as specimens for preservative treatment. High concentration (1.82% active ingredients) of copper azole preservative was used. Both ends of specimens were sealed with urethane resin prior to steam injection to prevent penetration of liquids from the ends.

A through-hole was made using a CO_2 laser (Marubeni Rofin Co. Ltd., RS1700 SM) on the radial surface of lumber by controlling irradiating time with the power of 1500 W. The incising pattern was the same for all species (Islam et al 2007). The numerical control (NC) table was used to control different incising densities, ie 5000 holes/m^2 for sugi and 10,000 holes/m^2 for Douglas-fir. Moisture content was measured before and after steam injection and dipping.

Steam (steam temperature of 110°C for a hot plate temperature of 120°C) was injected into laser-incised specimens for 20 and 200 min for dry and green lumber, respectively, by a steam injection press (Kitagawa Seiki Co. Ltd., Fuchu, Japan; VH2-1449). Both temperatures were controlled by controlling steam pressure with continuous observation of pressure sensors. Specimens were dipped into preservative for 12 h immediately after steam injection. Experiments were repeated four times.

Pressure and temperature sensors were set at sample center, and data were collected at every 10 s. Data collection started from the beginning of steam injection to 60 and 340 min of continuous dipping for dry and green specimens, respectively.

Gross chemical retention, copper detection, and preservative penetration were measured to evaluate success of the preservation process. Specimens were wiped lightly after dipping to remove excess solution from the surface. Copper detection was analyzed by an X-ray florescence analyzer (MESA-500; Horiba, Kyoto, Japan). For this analysis, a 30-mm sample was cut from the specimen and oven-dried. Three blocks (45 × 30 × 13 mm) were cut from this sample starting from the laser irradiating surface, then at 13 mm, and finally at the center. The gross chemical retention was calculated as stated by Islam et al (2008).

Specimens were sealed in a plastic bag and conditioned for 2 wk at room temperature after preservative impregnation for its fixation. Specimens for the penetration test were collected from the center of each treated specimen. Preservative penetration (Cu) was measured based on the color indicator on the freshly cut wood surface of treated lumber as described by the American Wood Preservers' Association (AWPA) in both longitudinal and tangential surfaces for all specimens with a scanner and Adobe Photoshop software (Adobe Systems Incorporated, San Jose, CA) (Islam et al 2009). Total chemical retention (kg/m^3) was determined by weighing each sample before and after dipping to determine solution uptake (Islam et al 2009).

RESULTS AND DISCUSSION

Temperature and Pressure in Wood

Steam carries heat into the wood through the incising holes. Heat removes air and vapor from the cell lumen during steam injection in dry lumber. In green wood, heat evaporates free water as well as replaces air from the cell lumen. The sample absorbed preservative during dipping. Subsequently, temperature decreased and negative pressure occurred. In green samples, the temperature increase and decrease were not the same for Douglas-fir and sugi. Douglas-fir had a steeper temperature change than sugi in both steam injection and dipping (Fig 1). After steam injection, temperature was slightly higher in Douglas-fir than in sugi. This might be because of lower initial moisture content of Douglas-fir (Fig 2). Sugi had slightly higher pressure than Douglas-fir for green samples. Both species showed slight negative pressure for a short time.

There was no difference in temperature increase or decrease for dry Douglas-fir and sugi during steam injection and dipping (Fig 2). Rise of pressure during steam injection was also similar for the two species. However, sugi had greater negative pressure than Douglas-fir in dipping, which was retained for a very long time. Even when the sensors were removed, there was negative pressure (Fig 2). This greater negative pressure of sugi might be related to lower incising density compared to Douglas-fir, lower initial moisture content, and the permeability of sugi.

Douglas-fir had similar negative pressure in dipping for both green and dry samples because

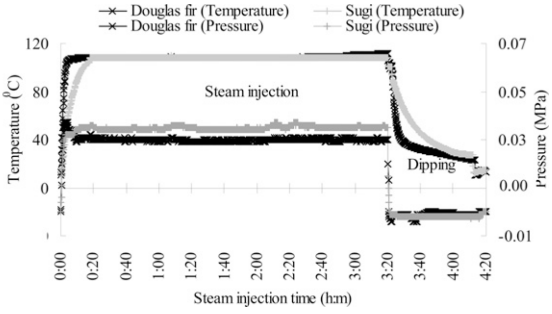

Figure 1. Change of temperature and pressure during steam injection and dipping of green Douglas-fir and sugi.

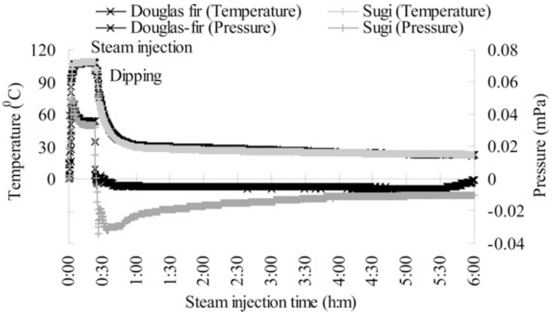

Figure 2. Change of temperature and pressure during steam injection and dipping of dry Douglas-fir and sugi.

permeability does not differ much with moisture content. Rhatigan and Morrell (2003) also reported similar results in which preservative penetration did not vary with moisture content. However, in sugi, permeability differs significantly with moisture content. Sugi has a high pit aspiration ratio up to 80% until moisture content decreases to FSP (Matsumura et al 1994; Fujii et al 1997), which causes a significant decrease in permeability (Phillips 1993; Matsumura et al 1994). MacLean (1941) stated that thermal conductivity is the function of moistute content and density. Moisture content and density of the lumber in this study varied (within and between species), and thus, thermal conductivity also varied. This might be another cause of the early-phase temperature variation inside the wood, which also directed the pressure variation.

During steam injection, moisture content of dry and green lumber of Douglas-fir and sugi was

Table 1. Moisture content of lumber at different stages of treatment.

Species	Lumber type	Before incising	After steam injection	After dipping
Douglas-fir	Dry	18	24	91.3
	Green	35	17	85
Sugi	Dry	11	17	150
	Green	74	60	166

changed. Dry lumber absorbed 6% moisture for both species. However, green lumber released 18 and 14% moisture during steam injection for Douglas-fir and sugi, respectively (Table 1). This difference in moisture content released from green lumber may be related to higher incising density and lower initial moisture content of Douglas-fir.

Preservative Retention

Preservative retention was higher in sugi than in Douglas-fir, and dry lumber absorbed more preservative than green regardless of species (Fig 3). When wood density is high, lumen volume is low (Simpson 1993) and preservative absorption is therefore restricted. This might be the cause of higher preservative retention of sugi compared to Douglas-fir both in green and dry lumber. Retention was also higher in dry lumber than the green one (Islam et al 2008). Drying of wood significantly increases percentage of void volume by removing moisture from wood. These voids fill with preservative at the time of treatment, causing higher retention by dry lumber. FSP (Skaar 1984) should provide ideal conditions for preservative flow through the lumens as well as for the diffusion of waterborne preservatives in the cell wall, thus ensuring higher preservative retention (Bamber and Burley 1983; Kumar and Morrell 1989; Eaton and Hale 1993). However, high moisture content of green lumber hindered preservative retention. Preservative retention varied from 4.63 kg/m^3 for green Douglas-fir to 6.63 kg/m^3 for dry sugi. Still, the lowest retention (4.63 kg/m^3) was much higher than the required retention level for ground contact application (3.36 kg/m^3) prescribed by the AWPA (Lebow 2004). With the exception of green Douglas-fir, retention was much higher than the prescribed retention level (4.97 kg/m^3) for permanent wood foundation/structure. Retention level was lower when a lower concentration of preservative was used to treat the wood (Islam et al 2008).

Copper detection was also analyzed by the X-ray fluorescence analyzer. Copper detection decreased from 47.6 to 21 cps/μA for the laser-irradiated surface of green Douglas-fir to the central samples of green sugi, respectively. It was found that copper detection was higher in Douglas-fir than in sugi, and in green lumber, copper detection was higher than the dried one (Fig 4). As expected, the outer samples had more copper than the inner ones. However, for inner samples (at 13 and 52 mm), the difference in copper was more substantial in sugi than in Douglas-fir. For sugi specimens, heartwood was present at the center surrounded by a very thin layer of sapwood, whereas Douglas-fir was

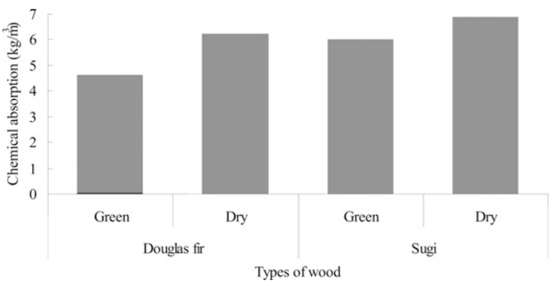

Figure 3. Retention of preservative treated by the passive impregnation method.

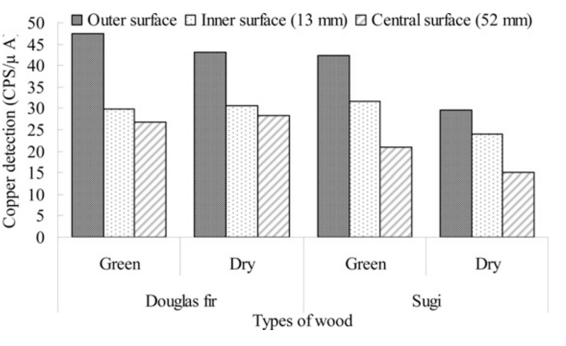

Figure 4. Copper detection from different samples and different positions by X-ray florescence analyzer.

quartersawn and mostly heartwood. This might be the cause of the lower copper detection in the inner part of the sugi specimen.

Preservative Penetration

There was little to no difference in preservative-penetrated area for a cross-section of both green and dry lumber of Douglas-fir and sugi (Fig 5). Penetrated area was almost 100% for all cases. The penetrated area of longitudinal section for different surfaces was similar to that of the cross-sectional surface of green and dry lumber for both species (Fig 6).

The penetrated area was similar to the trend reported by Hattori et al (2007) and Islam et al (2009), but it was higher in this study. Preservative penetrated both in sapwood and heartwood almost completely, and it was very difficult to identify the sapwood and heartwood after treatment. Color change in wood caused by preservative was more apparent along the incising hole created by CO_2 laser. These holes exposed additional area for liquid penetration in both longitudinal and lateral directions within the lumber.

Color change caused by preservative penetration in both green and dry samples of Douglas-fir and sugi was prominent at any depth of the sample and was detectable without applying a color indicator (Fig 7).

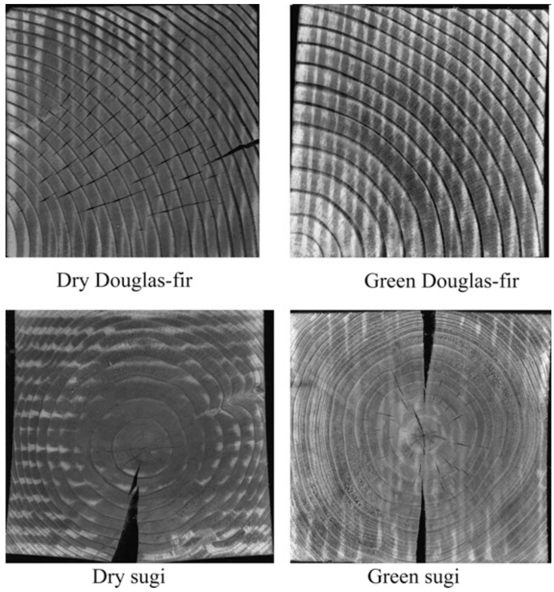

Figure 7. Penetrated area of preservative at cross section for dry and green lumber of Douglas-fir and sugi.

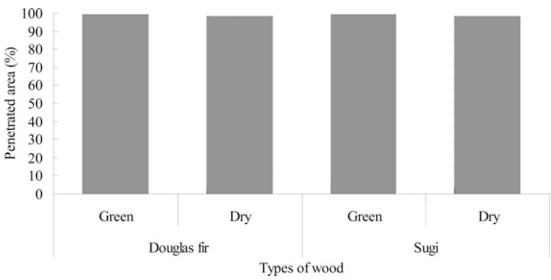

Figure 5. Penetrated area of preservative at the cross-sectional surface for dry and green lumber of Douglas-fir and sugi.

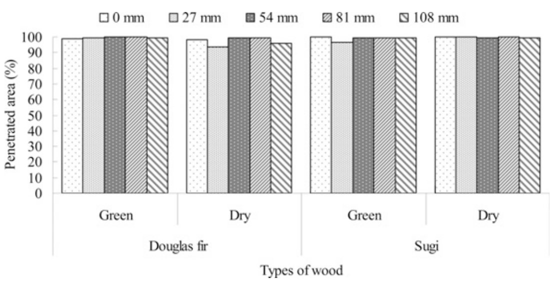

Figure 6. Penetrated area of preservative at longitudinal surfaces for dry and green lumber of Douglas-fir and sugi.

SUMMARY AND CONCLUSIONS

Preservative-treated wood is produced typically by pressure treatment, in which chemicals are driven a short distance into the wood using a special vessel that combines pressure and vacuum. Although deeper penetration is highly desirable, the impermeable nature of dead wood cells makes it extremely difficult to achieve anything more than a thin shell of treated wood. However, preservative impregnation throughout the impermeable wood is possible when it is treated by the passive impregnation method with a high concentration of preservatives. The specific findings of this study are as follows:

A. Required retention of preservative for using the lumber in permanent structural component in ground contact application can be achieved by the passive impregnation method for both green and dry lumber.
B. Almost 100% penetration of preservative can be attained by the passive impregnation method for both green and dry lumber.
C. Temperature increase and decrease in steam injection is related to permeability, initial moisture content, and density of wood.

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