J Wood Sci (2009) 55:441–445
DOI 10.1007/s10086-009-1056-y

ORIGINAL ARTICLE

Ikuo Momohara · Shuetsu Saito · Wakako Ohmura
Makoto Kiguchi

Effect of drying method as a pretreatment on CUAZ preservative impregnation in Japanese cedar logs

Received: June 12, 2009 / Accepted: 16 July, 2009 / Published online: October 15, 2009

Abstract Green Japanese cedar logs 2 m in length and 18 cm in diameter were dried to a mean moisture content of less than 30% by either air drying or kiln drying. Dried logs were impregnated with copper azole (CUAZ) solution according to Japanese Industrial Standard (JIS) A9002. Preservative absorption was calculated from the log weight before and after preservative impregnation. Impregnated logs were then dried in the air and cut at the center to determine preservative penetration. The penetration area was determined after visualizing the preservative with chrome azurol S. The visualized area indicated that the preservative solution penetrated into the sapwood portion of almost all the air-dried logs. However, the kiln-dried logs did not show full penetration into the sapwood portion. The visualized area of some kiln-dried sapwood showed a penetration value of less than 80%, which is the minimum requirement set by the Japanese Agricultural Standard (JAS) for sawn timber. Statistical analysis showed that penetration in the air-dried sapwood was significantly better than that in the kiln-dried sapwood. It was concluded that air drying is more favorable than kiln drying as the predrying method for CUAZ impregnation. On the other hand, preservative absorption was not affected by the drying method.

Key words Preservative · Impregnation · Penetration · Absorption · Wood drying

Introduction

Wood is regarded as a carbon sink and a useful material for mitigating global warming.[1–3] Therefore, many attempts have been made to replace steel and concrete with wood.[4–7] Wooden guardrails are one of the products in which steel and concrete are replaced with wood.[8,9] Several types of guardrails with wooden beams have been developed and confirmed to satisfy the Japanese regulations for guardrails.[8]

Although wooden guardrails can be considered as a carbon sink, they are also a source of carbon dioxide emission. So, in view of mitigating global warming, it is very important to prolong the service life of the guardrails and delay the emission of carbon dioxide gas. Extended service life is expected through preservative treatments.[10]

Preservative treatment in Japan used to be applied to railroad ties and utility poles.[11] Many studies were carried out to estimate and improve the efficacy of preservative treatment, and the results revealed that the wood moisture content affects preservative impregnation and thus wood with high moisture content is not suitable for preservative impregnation.[11] Therefore, it has been recommended that the moisture content be reduced before preservative treatment.[12–17]

Although inadequate drying may result in insufficient impregnation, these results were derived by a test using chromated copper arsenate (CCA) or creosote oil. It is not known if dried logs can be properly impregnated with post-CCA preservatives such as copper azole (CUAZ), ammonium copper quaternary compound (ACQ), or alkyl ammonium compound (AAC). In addition, the wood-drying method has been improved from air drying to kiln drying.

This study experimentally investigated the impregnation of dried Japanese cedar logs with CUAZ, the results of which are presented here. The effect of the drying method on impregnation is also discussed.

Materials and methods

The scheme of this experiment is shown in Fig. 1. Sixty green logs of Japanese cedar (*Cryptomeria japonica*) were randomly divided into two groups each consisting of 30

I. Momohara (✉) · S. Saito · W. Ohmura · M. Kiguchi
Forestry and Forest Products Research Institute, 1 Matsunosato, Tsukuba 305-8687, Japan
Tel. +81-29-829-8298; Fax +81-29-874-3720
e-mail: momohara@ffpri.affrc.go.jp

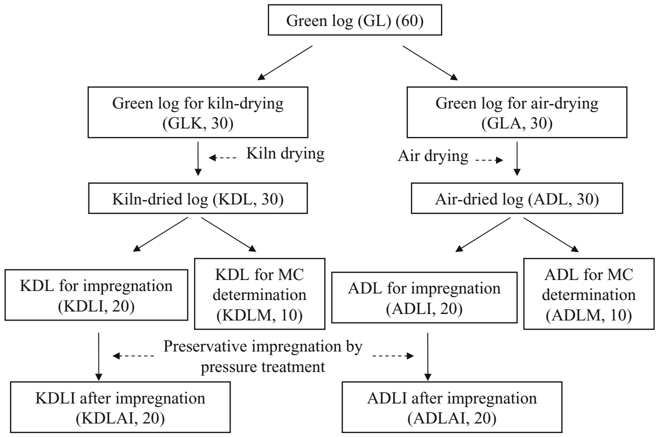

Fig. 1. Experimental scheme. Abbreviations and number of logs are shown in *parentheses*

Table 1. Schedule of kiln drying

Step	Period (days)	Dry bulb temperature (°C)	Wet bulb temperature (°C)	Relative humidity (%)	Treatment
1	0.5	85	85	100	Steaming
2	1	70	67	87	
3	2	71	67	83	
4	2	73	67	76	
5	2	75	67	69	Drying
6	2	77	68	65	
7	2	79	68	59	
8	2	80	68	57	
9	0.5	80	75	80	Conditioning

green logs. The green logs (GL) in each group were weighed and dried by one of two drying processes.

One of the drying processes was air drying, which was carried out at the Forestry and Forest Products Research Institute (FFPRI) in Tsukuba City from July to October in 2007. The green logs for air drying (GLA) were laid out under a roof and dried for 4 months. The other process was kiln drying, which was conducted at FFPRI using a conventional drying chamber according to the drying schedule shown in Table 1.

After the drying process, both the air-dried logs (ADL) and the kiln-dried logs (KDL) were weighed, and their moisture content was measured using a Kett HM-520 wood moisture meter. Measurements were taken at 12 points (Fig. 2). After the moisture content was determined using the moisture meter, one-third of the logs were randomly selected for determining the moisture content by the oven-dry method [air-dried log for moisture content determination (ADLM) and kiln-dried log for moisture content determination (KDLM) in Fig. 1].

Moisture content of selected logs was determined at the center and at 50 cm from both ends. Wood disks about 2 cm thick were prepared from these positions. Wood strips (width about 2 cm) were made from each disk (Fig. 3). Small specimens were prepared from each strip and weighed (*W*w). The specimens were dried for about 24 h in an oven at 105° ± 2°C and then weighed as dry mass (*W*d). The

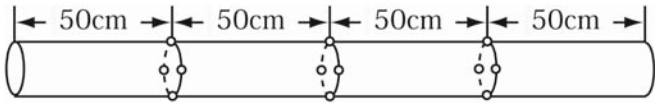

Fig. 2. Points of moisture content measurement. *Open circles* indicate the points where moisture content was measured with a moisture meter

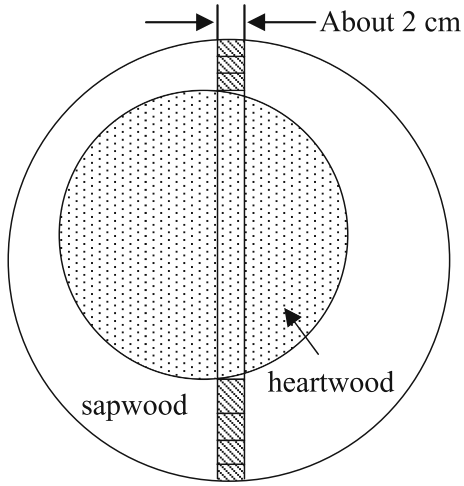

Fig. 3. Preparation of specimens for moisture content determination by an oven-dry method

moisture content of each specimen was calculated from the following equation:

$$\text{Moisture content (\%)} = (W_w - W_d) \div W_d \times 100 \quad (1)$$

Nonselected logs (ADLI or KDLI) were separately impregnated with CUAZ solution containing 0.32%–0.39% CuO and 0.002% cyproconazole according to Japanese Industrial Standard (JIS) A9002 (2005).[16] Both impregnation processes consisted of the following three steps: preliminary vacuum step (0.5 h, 0.0 MPa), impregnation step (5 h, 1.55 MPa), and preservative withdrawn step (1 h, 0.0 MPa). After the impregnation process, the air-dried logs after impregnation (ADLAI) and the kiln-dried logs after impregnation (KDLAI) were weighed again, and the absorption of preservative solution was calculated from the weight of the logs before and after the impregnation. The impregnated logs were laid out under a roof and seasoned for several months. Wood disks were cut from the center of the impregnated dried logs and used for determining the preservative penetration according to the Japanese Agricultural Standard (JAS) for sawn timber.[18] To visualize the preservative, 0.5% chrome azurol in 1% sodium acetate solution was sprayed on the surface of each disk. The sprayed disks were dried in a ventilated room for 1 day.

Calculation of percentage of penetration against sapwood area was conducted using a CanoScan 9950 F flat bed color scanner (Canon) and ImageJ image analysis software (National Institutes of Health, Bethesda, MD, USA).[19] The scanned data containing whole end-grain images were first divided into sapwood and heartwood images by a visual check, and the sapwood image was used for the next calculation. The sapwood area was determined using the software. The preservative penetration area was also calculated using the software, as follows: the RGB image was first divided into three grayscale images, one each for the red, blue, and green channels. Next, a subtracted image of the red channel minus the blue channel was calculated and a threshold was set on the subtracted image. The threshold level was adjusted to that where the selected area was equal to the colored area of the original image.

All statistical analyses were performed using JMP 8.0 (SAS Institute, Cary, NC, USA). Significance level was set at 0.05 throughout all analyses.

Results and discussion

To investigate the effect of the drying method on preservative impregnation, green logs of Japanese cedar were divided into two groups and subjected to either air drying or kiln drying followed by preservative impregnation. Mean weight of green logs for GLA was 37.1 kg with a standard deviation of 5.9 kg, and that for GLK was 38.4 kg with a standard deviation of 4.1 kg. Statistical analysis by Student's *t* test suggested that there was no significant difference in average weights between these two groups. Two groups of logs with almost the same mean weight were subjected to further study.

The logs of each group were dried by the air-drying or kiln-drying procedure. Table 2 shows the weight and moisture content of the logs after each drying procedure. Statistical analysis indicates that there was no statistical significance in the mean weight of logs between the two groups. The mean dimensional weight of the ADL and the KDL was less than 500 kg/m^3. However, the maximum dimensional weight of the two groups was greater than 500 kg/m^3. JIS A9002 suggests that Japanese cedar should be dried to a dimensional weight of less than 500 kg/m^3 before impregnation.[17] The data on dimensional weight indicated that some logs were not sufficiently dry to be impregnated with preservative.

Mean moisture content of the logs calculated from data measured by the Kett HM-520 moisture meter is also shown in Table 2. Mean moisture content and standard deviation of the ADL were slightly higher than that of the KDL. The maximum moisture content measured by the moisture meter was 94%, which is a great deal higher than that expected after air-drying for several months. Rainfall or dew may have increased the moisture content of the log surface, but the reason for such extremely high moisture content remains unclear.

Mean moisture content of the logs was also determined by the oven-dry method. The results are also shown in Table 2. The maximum moisture content given by the oven-dry method was 26.5% and 28.9% for the ADLM and KDLM, respectively. These values were almost the same as the fiber saturation point. Therefore, it is suggested that the sapwood portion of the logs used for preservative impregnation (ADLP and KDLP) had practically no free water. This finding was also confirmed by mean moisture content and standard deviation of ADLM and KDLM. In the case of ADLM, for example, a mean moisture content of 20.4% and standard deviation of 2.5% suggests that 99.7% of sapwood had a moisture content of less than 26.9%, because about 99.7% of sapwood should have a moisture content within 3 standard deviations of the mean moisture content.

The maximum values determined by the oven-dry method were much lower than those observed by the moisture meter. This fact suggests that the high moisture content observed by the moisture meter was not caused by the high moisture content of the sapwood portions; it might have been affected by high moisture content on just the surface of the logs or in the heartwood portion. Statistical analysis indicates that the sapwood in ADLM showed significantly higher mean moisture content than that in KDLM.

The results of preservative impregnation are shown in Figs. 4 and 5. The weight of logs before preservative impregnation significantly affected preservative absorption. Higher weight appeared to result in lower absorption amount. The correlation coefficient between weight and absorption was –0.82. Moisture content also significantly affected preservative absorption (correlation coefficient, –0.71). Mean preservative absorption of ADLAI was 572 kg/m^3 with a standard deviation of 78 kg/m^3, and that of KDLAI was 583 kg/m^3 with a standard deviation of 53 kg/m^3. Statistical analysis suggests that there was no statistical significance in preservative absorption between the logs dried by air drying and those dried by kiln drying.

The effect of the drying method on preservative penetration is shown in Fig. 5. The weight of logs before impregnation is plotted against the percentage of preservative penetration area in the sapwood. The figure clearly shows that there is no relationship between log weight and percentage of penetration area. It is also shown that there is no relationship between mean moisture content and percentage of penetration. On the other hand, the percentage of penetration appeared to be affected by the drying method. All ADLAI showed almost full penetration, but one-fourth

Table 2. Weight, dimensional weight, and moisture content of logs after drying procedures

Sample name	Mean weight (kg)	Dimensional weight (kg/m^3)	Mean moisture content (%)	
			Moisture meter method	Oven-dry method
Air-dried logs	22.5 (2.8)	442 (55)	17.3 (7.5)	20.4 (2.5)
Kiln-dried logs	23.4 (2.1)	460 (41)	13.8 (2.5)	16.7 (3.4)

Standard deviations are shown in parentheses

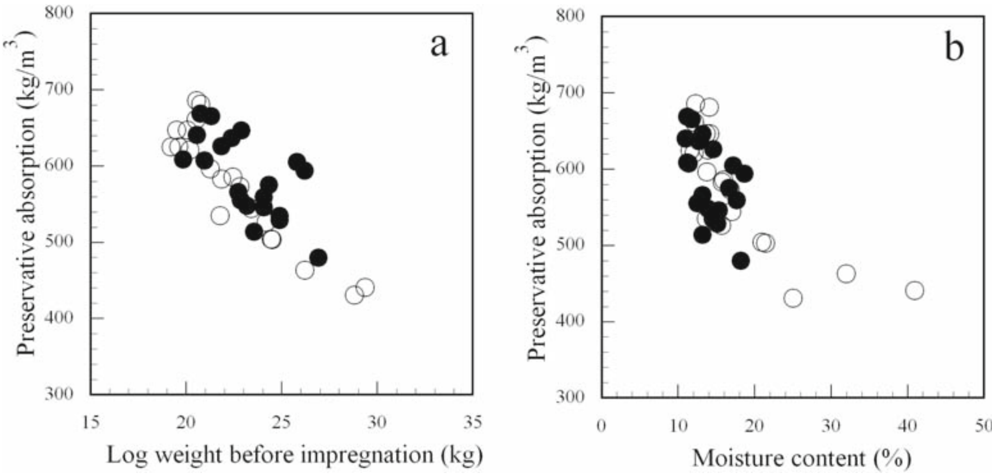

Fig. 4. Factors affecting preservative absorption. Moisture content was measured by a moisture meter. **a** Effect of log weight on preservative absorption. **b** Effect of moisture content on preservative absorption. *Open circles*, air-dried log; *filled circles*, kiln-dried log

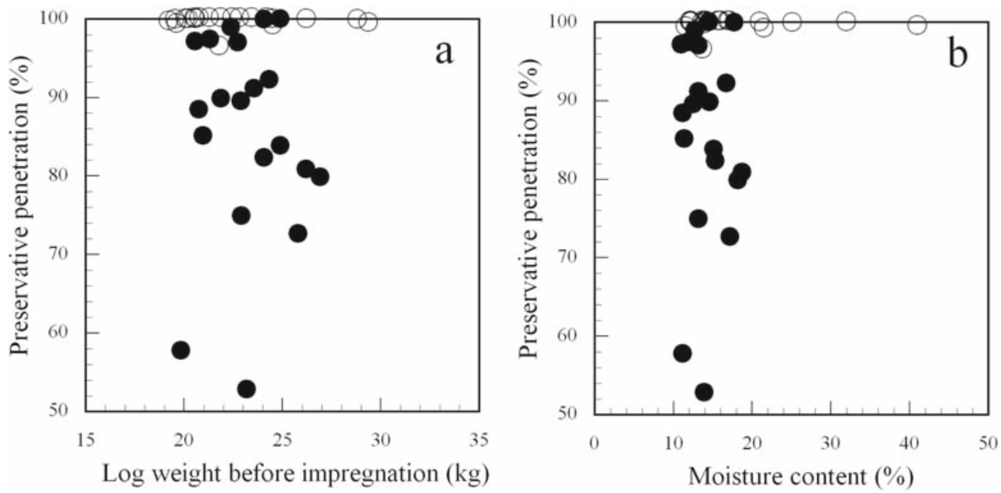

Fig. 5. Factors affecting preservative penetration. Moisture content was measured by a moisture meter. **a** Effect of log weight on preservative penetration. **b** Effect of moisture content on preservative penetration. *Open circles*, air-dried log; *filled circles*, kiln-dried log

of the KDLAI showed penetration of less than 80%, which is the minimum requirement set by the JAS for sawn timber. To clarify the effect of the drying method on preservative penetration, the percentage of penetration was statistically analyzed. The average value of penetration in the ADLAI was 99.6% with a standard deviation of 0.8%, and that in the KDLAI was 85.5% with a standard deviation of 13.2%. Student's *t* test clearly indicates that penetration in the air-dried logs is significantly better than that in the kiln-dried logs.

The importance of moisture content control before preservative impregnation is well documented.[12–17] However, the results of this study clearly indicate that moisture content control is necessary to ensure a certain level of preservative absorption but is not sufficient to assure adequate penetration. To achieve an adequate penetration level, air-drying before preservative impregnation is necessary. This study also reveals that dimensional weight, moisture content, and preservative absorption are not satisfactory indicators for judging preservative penetration. There is no correlation between these indicators and preservative penetration in the dried log tested in this study (Figs. 5, 6).

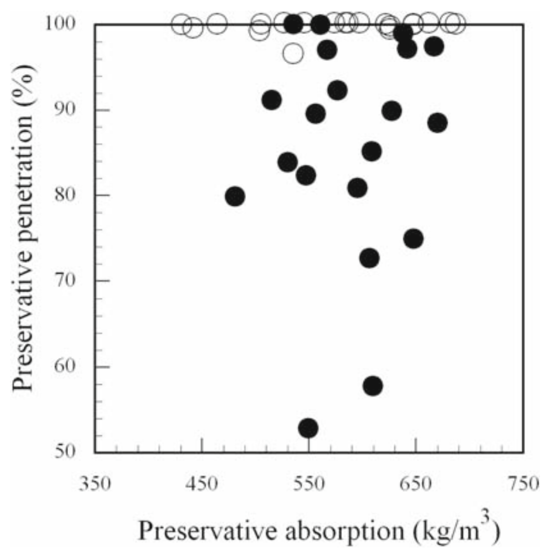

Fig. 6. Relationship between preservative absorption and penetration. *Open circles*, air-dried log; *filled circles*, kiln-dried log

Therefore, it is impossible to eliminate dried logs with poor penetration through the screening of these indicators. It will be necessary to development reliable new indicators for judging penetration.

The reason why the kiln-dried logs showed inferior penetration remains unclear. Lower moisture content of the kiln-dried sapwood might have resulted in an increase of aspirated pits,[20–22] which is known to reduce the permeability of logs. Or, the drying method might have affected the number and depth of surface cracks and checks occurring during the drying procedure. Further study will be required to reveal the factors for reduced permeability in kiln-dried logs.

Regarding energy consumption, air drying is preferable to kiln drying. In the case of kiln drying, fossil fuel resources are required to supply the latent heat of evaporation.[23] In addition, part of the energy supplied by fossil fuel is lost in the process of kiln drying such as heat loss from the dryer, heat loss associated with vent air, and steam delivery loss.[23] It was shown that about 80 kg carbon dioxide is released when drying 1 m^3 Japanese cedar wood.[24] In addition to this advantage of air drying, this study revealed that air drying is suitable for producing dried wood with good treatability. Therefore, it is concluded that air drying followed by preservative treatment will help mitigate global warming.

Although air drying is more environmentally friendly than kiln drying, it is also true that air drying takes longer to produce dried logs suitable for preservative impregnation. Our next task is to find the optimal process for producing dried wood with high treatability using less energy and in a shorter drying period.

Conclusions

Preservative penetration in sapwood and preservative absorption were investigated using dried Japanese cedar logs and CUAZ solution. It is concluded that air drying is a better pretreatment than kiln drying for CUAZ impregnation to mitigate global warming, from the following results obtained:

1. Absorption of preservative solution significantly decreased with increase of dimensional weight. Preservative absorption appeared to lessen with an increase of moisture content.
2. Preservative penetration did not correlate with moisture content, dimensional weight, and preservative absorption.
3. Preservative penetration in the air-dried logs was significantly higher than that in the kiln-dried logs.

Acknowledgments We are deeply grateful to Xyence Co. Ltd. for their help in assisting with preservative impregnation. We also thank Mr. Tomoya Kawada and Mrs. Etsuko Shirakawa for their help in sample preparation. This study was supported by the program "Research Project for Utilizing Advanced Technologies in Agriculture, Forestry and Fisheries" and "Research and development projects for application in promoting new policy of Agriculture Forestry and Fisheries" by the Ministry of Agriculture, Forestry and Fisheries of Japan.

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