Effect of High-Temperature Treatment on Wood Durability against the Brown-rot Fungus, *Fomitopsis palustris*, and the Termite, *Coptotermes formosanus*.

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ABSTRACT

High-temperature kiln drying has become common in Japan to save drying time. This process is thought to reduce wood durability, but this mechanism has not been clear. In this study, small air-dried specimens were subjected to a heat-treatment in different conditions to clarify the effect of the treatment temperature and time on wood durability. Air-dried Japanese cedar (*Cryptomeria japonica*) blocks exposed to a saturated vapor at 105 °C to 150 °C for 6 to 72 hours were subjected to an accelerated decay test using the brown-rot fungus, *Fomitopsis palustris*, or an anti-termite test with *Coptotermes formosanus*. The result revealed that the heat-treatment at 135 °C or above invested the wood block with the fungal resistance. Both the treatment temperature and period affected the fungal resistance. The fungal resistance became highest after the heat-treatment at the highest temperature for the longest period. Contrarily, the termite resistance seemed to be lost by the treatment.

INTRODUCTION

Several heat-treatment processes have been developed in Europe to add durability to non-durable wood. These European processes treat sawn wood at elevated temperatures. The main differences among the processes can be seen in the process conditions (process steps, oxygen or nitrogen, steaming, wet or dry process, use of oils, steering schedules etc.) (Militz 2002). The treatment temperatures are in common in the range between 160 °C to 190 °C (PLATO-process) (Tjeerdsma *et. al.* 1998), 200 °C to 240 °C (Retification process and Bois perdure) (Kamdem *et. al.* 2002), 180 °C to 220 °C (Oil-heat treatment) (Rapp and Sailer 2000) and 185 °C to 215 °C (Thermo Wood process) (Finnish Thermowood Association 2003).

On the other hand, high-temperature kiln drying has been adopted in Japan to shorten the period of wood drying (Hisada 2001). In this process, timber is placed in a kiln held at a temperature over 100 °C. The temperature is much lower than the European thermal processes (Militz 2002) but it seems high enough to affect the characteristics of the timber, such as strength and dimensional stability. Much research has been conducted to evaluate the effect of high-temperature drying on the wood characteristics (Kobojima *et. al.* 2002, Ishikawa *et. al.* 2001). Research has also been carried out to clarify the effect of the high-temperature kiln drying on wood durability, and revealed it reduces fungal and termite resistance (Kurisaki *et. al.* 2001, Yamamoto *et. al.* 2001).

In spite of these negative results on durability of wood dried at high temperature, results from European processes suggests a possibility that a high-temperature wood drying process may invest wood with durability if the process keeps wood at a temperature high enough. In this study, the possibility was examined by using air-dried small wood blocks treated at different temperature. The effect of treatment temperature and time on wood durability is discussed in this report.

MATERIALS AND METHODS

Sample Preparation

Japanese cedar (*Cryptomeria japonica* D. Don) heartwood was used to investigate the effects of a heat-treatment on wood durability. Small stakes were cut from Japanese cedar heartwood and allowed to dry in a conditioned room at 20 °C 65 % RH for more than 6 months. The stakes were cut in size of 20 × 20 × 270 mm and placed in a HAST CHAMBER EHS-411M (ESPEC). Heat-treatments were carried out in the chamber at 105 °C to 150 °C for 6 to 72 hours with saturated steam. After the treatments, the stakes were cut into the sizes for an accelerated decay test and an anti-termite test (20 × 20 × 10 (L) mm).

Color Measurement

The color of the blocks was measured on the block surface with a Minolta spectrophotometer CM-508i. Colorimetric values were expressed as a function of L^*, a^* and b^*.

Anti-decay Test

The test blocks cut for the decay test were dried in a drying chamber at 60 °C for 2 days to measure their initial mass. They were kept in sterile bags and sterilized with a ethylene oxide gas sterilizer.

An accelerated decay test was carried out in culture bottles using the brown-rot fungus, *Fomitopsis palustris* (FFPRI 0507). The fungus maintained on PDA medium was inoculated on agar medium containing 2 % malt extract and 1 % peptone. When the fungus covered the medium surface, sterile plastic meshes were placed on the fungal mat, and the test blocks were put on the meshes. The culture bottles were placed in a conditioned room kept at 26 °C, and the blocks were subjected to the fungal attack for 8 weeks. After the fungal treatment, fungal hyphae were removed from block surfaces and the blocks were weighed. They were dried for 2 days at 60 °C and weighed again to calculate percentage of mass loss.

Anti-termite test

An anti-termite test was carried out according to Japan Wood Preserving Association Standard JWPS-TW-P.1 using *Coptotermes formosanus* Shiraki. The test blocks for the anti-termite test were dried at 60 °C for 2 days and weighed. The blocks were placed in the center on the plaster bottom of acrylic cylinders (90 mm in diameter and 50 mm in height) with the termites (150 workers and 15 soldiers). The cylinders were put in a plastic container bottom of which was covered with dampened cotton pads. The container was placed at 26 °C for 10 days. At the end of the test, the blocks were oven dried at 60 °C and weighed again.

RESULTS AND DISCUSSION

The wood blocks were treated at a temperature in a range of 105 °C to 150 °C. The temperature is higher than that in conventional wood drying but lower than that adopted in newly developed European thermal processes (Militz 2002). Another major difference is the length of treatment time. In conventional wood drying, timber was placed in a drying chamber and dried for 1 week while in the European processes timber was kept at a high temperature for a few hours. In this study, the wood blocks were heated for 6 to 72 hours. These values were larger than those of the European processes but smaller than the conventional drying processes.

Color Measurement

As mentioned in many research reports describing the high-temperature drying process or European thermal processes, the processes change the color of wood to a dark color (Kurisaki *et. al.* 2001, Militz 2002). Similar color change was observed in this study (Figure 1). To evaluate the difference between color before and after treatment, colors of the samples were measured with the spectrophotometer. Results are expressed as colorimetric values, L^*, a^* and b^*. As shown in table 1, L^* gradually decreased with the increase of treatment temperature. In other words, treatment at higher temperatures deprived more lightness of the sample. The lightness of the sample became about 75 % of the initial value after the treatment at 150 °C for 24 hours. The treatment might also affect values a^* and b^* but the effect was not clear.

Anti-decay Test

The anti-decay test was investigated by the accelerated decay test with the brown-rot fungus, *F. palustris*. White-rot fungus was not used because the wood sample used in this study, i.e. Japanese cedar, has fungal resistance against the white-rot fungus. Fungal resistance against only the brown-rot fungus was tested.

Firstly, the effect of the treatment temperature was investigated. Japanese cedar wood blocks treated at different temperature, 60 °C (untreated), 105 °C, 135

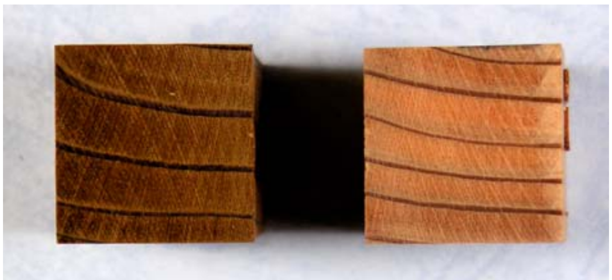

Figure 1 Photograph of the heat-treated samples
Left: sample treated at 135 °C for 72 hours
Right: untreated sample

Table 1 Colorimetric value safter the heat-treatment for 24 hours

Treatment temperature	L*	a*	b*
60 °C	52.3	11.2	19.4
105 °C	51.7	9.8	18.5
135 °C	48.8	6.4	19.8
150 °C	38.8	7.1	17.3

°C and 150 °C for 24 hours were subjected to the fungal attack for 8 weeks, and percentage of mass loss was calculated. As shown in figure 2, all treated samples showed smaller average mass loss than the untreated sample, especially, the samples treated at 150 °C which showed a mass loss of only one-third that of the untreated sample. A Student's unpaired t test revealed that there was a significant difference between the mass loss of the untreated sample and that of the samples treated at 150 °C ($P < 0.01$). On the other hand, no significant difference was observed between the mass loss of the untreated sample and that of treated samples at 105 °C or 135 °C ($P > 0.05$).

The improvement of the fungal resistance by the heat-treatment seems unclear at a temperature less than 135 °C. Therefore, a prolonged treatment was carried out to clarify the effect of the heat-treatment at a temperature less than 135 °C. In the prolonged treatment, a treatment temperature was set at 105 °C or 135 °C and treatment time was altered from 6 to 72 hours. As shown in figure 3, longer treatment at 135 °C resulted in higher fungal resistance. There exists a linear correlation between the treatment time and the percentage of mass loss ($r^2 = 0.96$). Significant difference ($P < 0.05$, unpaired Student's t test) was observed between the mass losses of three samples. The result clearly indicates the heat-treatment at 135 °C also improves wood durability against the fungus when wood is kept at this temperature for a long time. The heat-treatment at 105 °C, contrarily, did not improve the durability during the heat-treatment for 72 hours (data not shown).

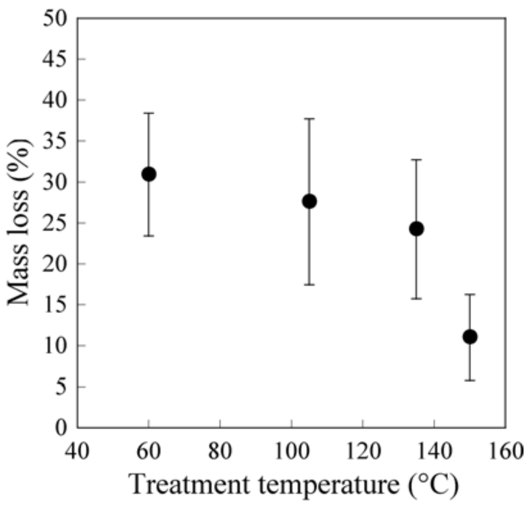

Fig. 2 Effect of treatment temperature on durability against the brown-rot fungus, *Fomitopsis palustris*.
Heat-treatment were carried out for 24 hours. Percentage of mass loss was calculated from the sample exposed to the fungus for 8 weeks. Bars indicate standard deviation (n=12).

Improvement of fungal resistance by the heat-treatment was not observed in previous studies using the timber dried by the high-temperature drying process (Kurisaki *et. al.* 2001, Yamamoto *et. al.* 2001). This discrepancy may be derived from differences among treatment temperatures and time. In the previous studies, large timber was subjected to the heat-treatment. As a result, inside of the timber was not affected by the heat. It has been reported that the temperature at the core of timber increase at a much slower rate than its surface (Yoshida *et. al.* 2000).

As shown in figure 2 and 3, the best result was obtained from the sample treated at 150 °C for 24 hours. However, even in the best results, percentage of mass loss is much higher than 3. Three percent mass loss is the maximum value for wood preservatives to be accepted as an approved wood preservative in the Japanese industrial standard K 1571 (1998). This fact suggests the heat-treatment at 150 °C for 24 hours is not enough to be substituted for preservative treatments.

Fungal resistance of wood treated by the European processes was reported by Welzbacher and Rapp (2002). Mass losses in the report were 1 to 3 % for *Coniophora puteana*, 5 to 8 % for *Coriolus versicolor*, and 6 to 15 % for *Oligoporus placenta*. These values were higher than that obtained for a sample treated with 2.8 % CCB. This result also indicates the European heat-treatments are not effective enough to be replaced with preservative treatment.

As indicated in figure 3, prolonged heat-treatment

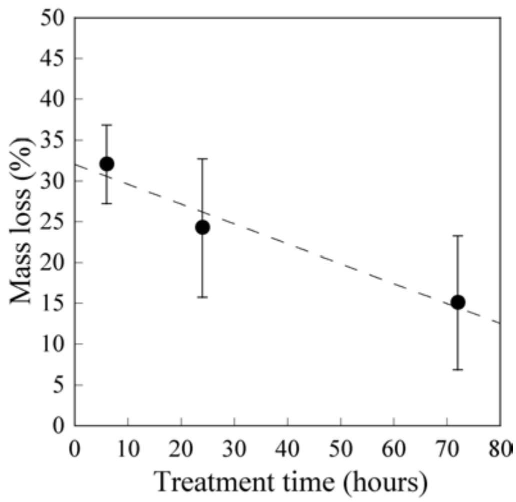

Fig. 3 Effect of treatment time on durability against the brown-rot fungus, *Fomitopsis palustris*.
Heat-treatment were carried out at 135 °C. Percentage of mass loss was calculated from the sample exposed to the fungus for 8 weeks. Bars and dashed line indicate standard deviation (n=12) and a regression line ($r^2 = 0.96$), respectively.

must be required to improve fungal resistance comparable to preservative treated wood.

Anti-termite Test

Effects of the heat-treatment on anti-termite activity were investigated with the termite, *C. formosanus*. Japanese cedar wood blocks treated at a different temperature were subjected to termite attacks. After 10 days exposure, percentage of mass loss was calculated. As shown in figure 4, treated samples at higher temperatures showed larger mass loss percentages than those treated at lower temperatures. Significant differences were observed between 60 °C and 135 °C or 60 °C and 150 °C ($P < 0.05$). In the case of Japanese Larch heartwood, steam treatment is reported to increase termite attraction (Doi *et. al.* 1998). Further study would be necessary to reveal the effect of the heat-treatment on anti-termite activity.

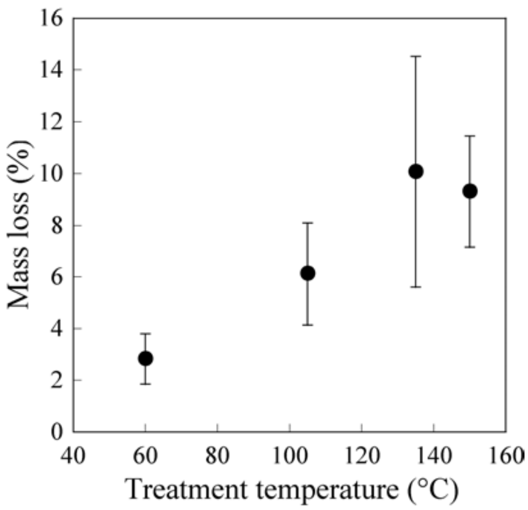

Fig. 4 Effect of treatment temperature on durability against the termite, *C. formosanus*. Samples were heated for 72 hours. Percentage of mass loss was calculated from the sample exposed to *C. formosanus* for 8 weeks. Bars indicate standard deviation (n=6).

CONCLUSION

Heat-treatments at more than 135 °C improve wood durability against the brown-rot fungus, *F. palustris*. Longer treatment at higher temperature results in stronger resistance against the fungus. The result indicates that the high-temperature wood drying has the potential to improve fungal resistance when the process maintains timber at an adequate temperature for a sufficient amount of time. Contrarily, the treatment seems to reduce anti-termite activity against *C. formosanus*.

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