J Wood Sci (2005) 51:526–530
DOI 10.1007/s10086-004-0684-5

ORIGINAL ARTICLE

Shuichi Doi · Masakazu Aoyama · Shigeru Yamauchi
Yasuji Kurimoto

Changes of decay and termite durabilities of Japanese larch (*Larix leptolepis*) wood due to high-temperature kiln drying processes

Received: March 31, 2004 / Accepted: October 25, 2004

Abstract We investigated the effects of high-temperature drying schedules (120°–130°C) on decay and termite feeding of Japanese larch timbers. Thermogravimetric analysis was conducted to investigate changes of the wood components. Decay and termite feeding tests showed that specimens dried under high-temperature schedules were susceptible against a decaying fungus *Fomitopsis palustris* and attacks from termites *Coptotermes formosanus* and *Reticulitermes speratus*. These drying schedules changed chemical components, which were suggested by the thermal analytical result compared to the control sample. The results of this study indicated that the acceleration of termite feeding takes place even under temperatures that are comparatively lower than that used in our previous research in which 170°C steaming treatment was applied to Japanese larch wood. Decay durability against a brown rot fungus also decreased, possibly from production of low molecular weight fragments when hemicellulose decreased during the high-temperature drying processes.

Key words Japanese larch · High-temperature drying · Decaying fungi · Termite feeding · Durability

Introduction

Our previous article reported that several wood species steamed at 170°C were preferably fed upon by two species of subterranean termites, *Reticulitermes speratus* (Kolbe) and *Coptotermes formosanus* Shiraki, under laboratory feeding tests.[1] From the results of studies on Japanese larch (*Larix leptolepis* (Sieb. et Zucc.) Gord.) heartwood, it was suggested that these phenomena were mainly due to the feeding stimulants produced by the steam treatment.[2,3] High-temperature drying distinctly decreased decay durability of Japanese cedar (*Cryptomeria japonica* D. Don) against a brown rot fungus, *Fomitopsis palustris* (Berk. et Curt.) Gilbn.& Ryv.[4]

Recently, high-temperature drying processes are applied to domestic wood species to supply dimension-stabilized and high-quality timbers for house construction in Japan. These timbers are often used as beams and poles and may be attacked by termites and wood-decaying fungi. Then, we investigated the effects of current drying schedules for larch timbers on termite feeding and decay. Thermal analysis was also conducted to investigate the changes of wood components in the drying processes that affect decay and termite durabilities.

Materials and methods

Tested timbers

Japanese larch logs of about 40 years of age were harvested in a forest in the Ina district of Nagano Prefecture, Japan. Boxed-heart square timbers, sized 105 × 105 × 4000 mm along the grain, were sawn from the logs. Average annual ring width of the timbers was 4.8 mm. They were dried under the following schedules using a kiln in a sawmill; 120°C drying: steamed at 95°C for 8 h followed by drying at 120°C for 48 h and at 105°C for 36 h; 130°C drying: steamed at 95°C for 8 h followed by drying at 130°C for 48 h. A 50°C temperature difference between wet bulb and dry bulb was maintained during both the drying processes. Controls were air-dried square timbers prepared from the same lot of logs. Target moisture content of all the timbers was 15%. Hereafter, we called the above samples, 120°C-samples, 130°C-samples, and control samples, respectively. Three

S. Doi (✉)
Graduate School of Life and Environmental Sciences, University of Tsukuba, Tsukuba 305-8572, Japan
Tel. +81-29-853-4646; Fax +81-29-855-2203
e-mail: sdoi@sakura.cc.tsukuba.ac.jp

S. Yamauchi · Y. Kurimoto
Institute of Wood Technology, Akita Prefectural University, Noshiro 016-0876, Japan

M. Aoyama
Department of Applied and Environmental Chemistry, Kitami Institute of Technology, Kitami 090-8507, Japan

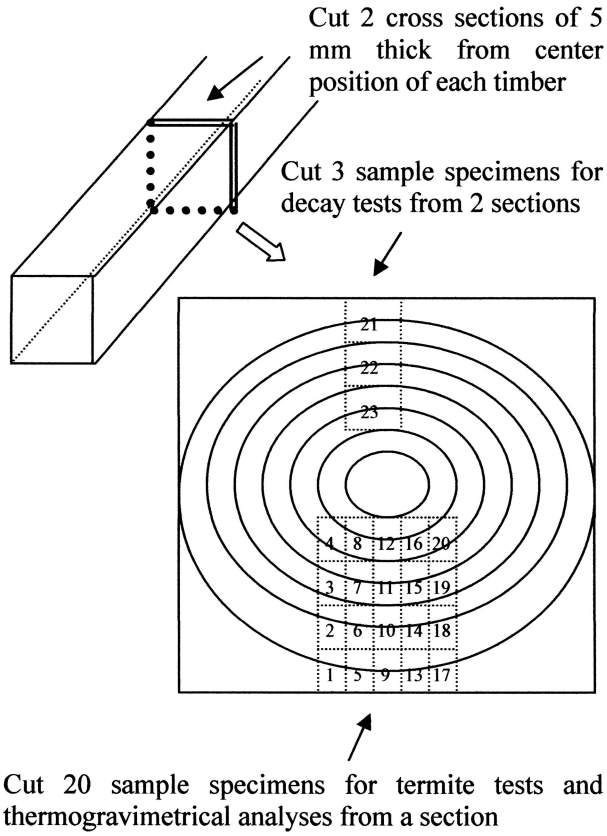

Fig. 1. Sampling diagram of each cross section for decay tests, termite feeding tests, and thermal analyses. Sample specimens No. 1–8 and 13–20 were used for feeding tests with *Coptotermes formosanus* and *Reticulitermes speratus*, respectively. Samples No. 9–12 were used for thermogravimetrical analyses, and No. 21–23 were used for decay tests. This figure does not correspond to actual dimensions and appearance

replications of each drying schedule were prepared for the following experiments.

Preparation of sample specimens

Two cross sections having 5-mm thickness were cut from the middle of the longitudinal direction of each square timber. Specimens for bioassays and thermal analyses were cut from one of the sections, as shown in Fig. 1. Three specimens (T15 × R15 × L5 mm) for decay tests were cut from the one side of the section (No. 21–23) while 20 smaller specimens (T3 × R13 × L5 mm) were cut from the opposite side (No. 1–20). Because these specimens were prepared from the same positions of 3 timbers per drying schedule, 3 matched specimens for all the positions were prepared for termite feeding tests and thermal analyses. From the remaining section, 3 specimens for decay tests were prepared to conduct 9 replications against each decaying fungus in the same manner as mentioned above.

Decay tests

Nine specimens (T15 × R15 × L5 mm, No. 21–23 by 3 timbers, Fig. 1) per drying schedule were exposed to a wood-decaying fungus growing on sandy media containing nutrient solution in 500-ml glass jars according to the modified JIS Z 2101-1994.[5] Test fungi were *Fomitopsis palustris* (Berk.et Curt.) Gilbn.& Ryv. FFPRI 0507 and *Trametes versicolor* (L.: Fr.) Pilat FFPRI 1030. Nutrient solution for *F. palustris* was tap water including 1% peptone and 2% malt extract, and that for *T. versicolor* contained 2.5% glucose, 0.5% peptone, and 1% malt extract. Exposure conditions were 90 days at 26°C in the dark. The mass losses of specimens were determined by weighing after oven drying at 60°C for 48 h before and after the decay procedure. Replications of the specimen were nine per fungus per drying schedule.

Feeding tests using two subterranean termite species

Tested termites were *Coptotermes formosanus* collected from a laboratory colony maintained at 26°C and 85% relative humidity (RH), and *Reticulitermes speratus* collected from an active wild colony on the campus of Akita Prefectural University, Akita, Japan.

The specimens were subjected to feeding tests to evaluate their susceptibilities against the above termite species. Specimen numbers for termite tests (Fig. 1) were as follows; No. 1–4 and No. 5–8 were subjected to choice and no-choice feeding tests using *C. formosanus*, respectively; No. 13–16 and No. 17–20 were subjected to *R. speratus* in the same manner as mentioned above.

A combination of the choice test comprised nine specimens, such as control 1-1 (log number – sampling position in a section), 2-1, 3-1, 120°C-samples 1-1, 2-1, 3-1, and 130°C-samples 1-1, 2-1, 3-1. These specimens were independently placed on plastic saucers and were circularly placed on 5-mm-thick wet sandy loam on a hard plaster layer in a 300-ml plastic cup. The cup had a 15-mm diameter hole stopped with absorbent cotton at the bottom for supplying water through a plaster layer from a moistened paper pad spread in a test chamber. Five hundred workers of *R. speratus* or 450 workers of *C. formosanus* were introduced into each cup. The chambers were maintained in a dark room at 26°C and 85% RH. After 4 days for *R. speratus* and 10 days for *C. formosanus*, the consumptions of specimens were calculated from the oven-dry weights after drying at 60°C for 48 h before and after the exposure. Three replications were conducted per set.

No-choice feeding tests were conducted according to the same procedure mentioned above except for the following; 100-ml plastic cups were used as test containers for 100 workers of *R. speratus* or for 50 workers of *C. formosanus*. The exposure period was 10 days for both the termite species. Three replications were used.

Statistical analyses

Duncan's multiple range tests were conducted using STATISTICA for Windows (Statsoft, Tokyo, Japan) for statistical analyses of all the data obtained from the decay and termite feeding tests.

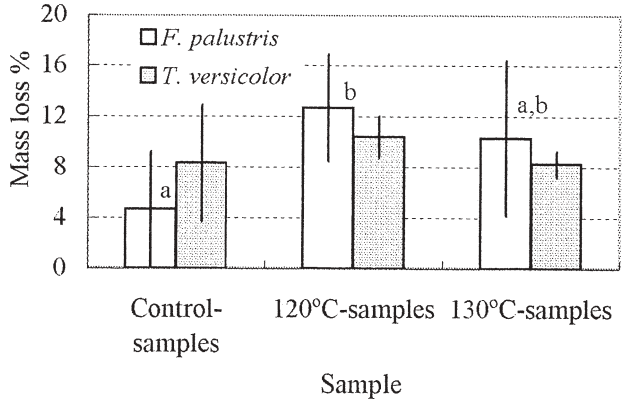

Fig. 2. Mass loss percentage of samples decayed by both fungi (*Fomitopsis palustris* and *Trametes versicolor*). *Vertical bars* show standard deviations. Significant differences ($P < 0.05$) were detected among the results marked with different letters (*a*, *b*) from Duncan's multiple range test

Thermogravimetric analyses

About 10 mg of wood meal, passed through a 200-mesh screen, was prepared from each specimen (No. 9–12 in Fig. 1) to determine thermogravimeteric spectra (MAC Science, TG-DTA2000S, Tokyo, Japan) at a programmed rate of 10°C/min from room temperature to 600°C under N_2 gas at a flow rate of 200 ml/min. Thermogravimetry was conducted once for each specimen.

Results and discussion

Decay durability

Figure 2 shows mass loss percentage of specimens decayed by *Fomitopsis palustris* and *Trametes versicolor*. In these cases, mass losses were calculated from nine specimens regardless of sampling position. After the exposure against *F. palustris*, there was significant difference ($P < 0.05$) in mass loss percentage between control samples and 120°C-samples, while no significant difference was detected between control samples and 130°C-samples as well as between 120°C-samples and 130°C-samples. No significant difference was observed in mass loss percentage of samples decayed by *T. versicolor* among the three sample types.

Figure 3 shows the distinct reduction of the differential thermogravimetry (DTG) peak (around 310°C) of the surface position of 130°C-samples compared with that of control samples. The other positions of the same sample and all the positions of 120°C-samples also exhibited the same decrease of the peak. These results mean that hemicellulose in both the high-temperature-dried woods was clearly degraded by the drying processes.[6] Decrease of decay durability is possibly due to the generation of low molecular weight sugar fragments from the hydrothermal changes of hemicellulose during the drying process including the steam treatment,[7,8] although different results were obtained between the two fungal species.

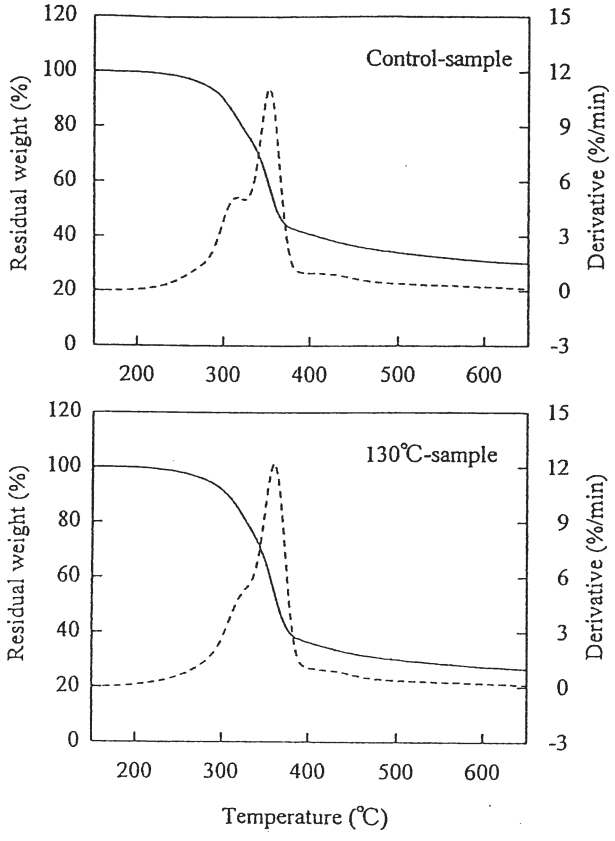

Fig. 3. Results of thermogravimetric analyses (TGA) of surface positions (sample specimen No. 9) of control samples (*upper*) and 130°C-samples (*lower*). *Solid lines* and *dotted lines* are the TGA and differential thermogravimetric (DTG) curves, respectively

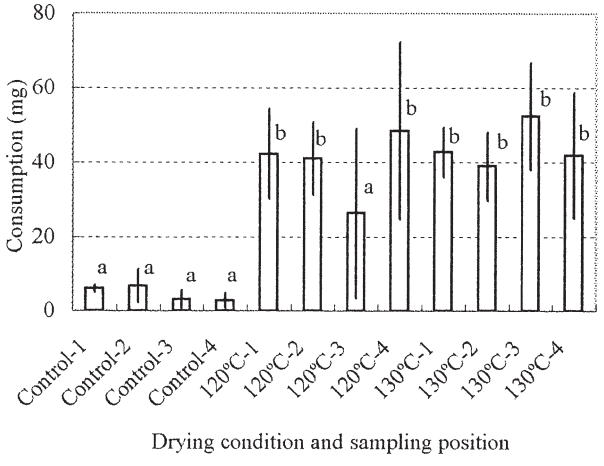

Fig. 4. Consumption of sample specimens by *R. speratus* in nine-choice feeding tests. *Vertical bars* show standard deviations. Significant differences ($P < 0.05$) were detected among the results marked with different letters (*a*, *b*) from Duncan's multiple range test

Termite durability

Consumptions of samples exposed to the nine-choice feeding tests with *Reticulitermes speratus* and *Coptotermes formosanus* are shown in Figs. 4 and 5, respectively. The

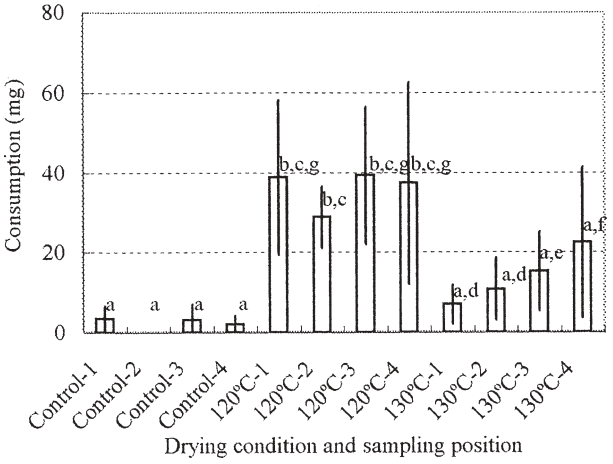

Fig. 5. Consumption of sample specimens by *C. formosanus* in nine-choice feeding tests. *Vertical bars* show standard deviations. Significant differences ($P < 0.05$) were detected among the results marked with different letters (*a–g*) from Duncan's multiple range test

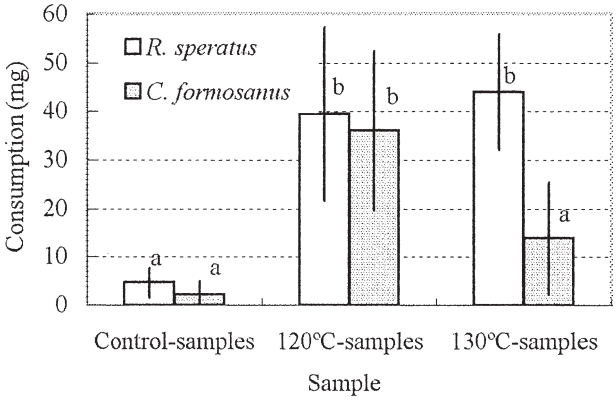

Fig. 6. Consumption of sample specimens by termites in nine-choice feeding tests using two termite species. *Vertical bars* show standard deviations. Significant differences ($P < 0.05$) were detected among the results marked with different letters (*a*, *b*) for each termite species from Duncan's multiple range test

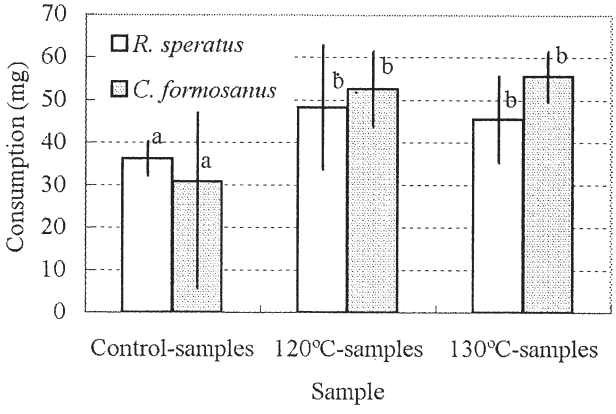

Fig. 7. Consumption of sample specimens by termites in no-choice feeding tests using two termite species. *Vertical bars* show standard deviations. Significant differences ($P < 0.05$) were detected among the results marked with different letters (*a*, *b*) for each termite species from Duncan's multiple range test

combinations tested were adopted for the following reason: because the rate of temperature increase at each position was possibly different due to the generation of inner pressure in square timbers under the high-temperature drying schedules,[9] the quantities of the feeding stimulants[2] produced or the changes of original feeding deterrent factors[3,10] were presumably different among these.

The result of the *R. speratus* test (Fig. 4) showed that almost all high-temperature-dried wood samples were attacked more severely than the control ones, although no significant difference of consumption was detected among sampling positions for each drying condition. The same phenomenon, that heat-treated wood was preferably fed upon, was already observed on 170°C steamed wood.[2] The no-choice feeding tests of samples prepared from the neighboring positions of samples for the choice feeding tests showed no clear difference even among the control and high-temperature-dried wood (data not shown).

Figure 5 shows the results of the nine-choice feeding tests using *C. formosanus*. Although no distinct difference of consumption was detected among the sampling positions in each drying condition, there was remarkable difference between the control and 120°C-samples ($P < 0.05$). The no-choice feeding test with this termite species showed specimens from the inner positions of the cross section had larger mass losses than those from the outer positions in the cases of both the high-temperature-dried wood specimens without significant difference (data not shown).

No significant difference of consumptions among the sampling positions of specimens by both termite attacks was possibly due to a smaller temperature gradient among these positions.

Data of choice feeding tests were combined regardless of sampling positions for each drying condition and were statistically analyzed to give the results shown in Fig. 6. The consumptions of 120°C-samples were significantly larger than those of control samples ($P < 0.05$) after the exposure to both termite species. These results mean that the 120°C drying process generated termite feeding stimulants and/or changed the feeding deterrents that are naturally contained in larch heartwood. We already reported that steaming treatment at 170°C for comparatively short times definitely affected the termite feedings of larch wood.[2] These results suggested that the same chemical reactions occur sufficiently at lower temperatures that are maintained for longer times. The same difference was detected between control samples and 130°C-samples exposed to *R. speratus* while no difference was observed in the case of *C. formosanus*. There is not enough information to explain this result within the scope of this experiment and further work would be required to clarity this result.

In the cases of the no-choice feeding tests, there were significant differences ($P < 0.05$) of consumptions between control samples and 120°C-samples or 130°C-samples exposed to both termite species when the data of each drying condition was individually combined and calculated (Fig. 7). It is assumed that termite feeding was accelerated by

softening of the timbers by high-temperature drying. However, this interpretation was neglected from our previous study in which there was no definite relationship between surface hardness and mass loss of specimen from termite feeding.[2] When Japanese larch sapwood was subjected to *R. speratus* after steam treatment followed by extractions with several solvents to remove extractives, all steam-treated specimens were dominantly fed upon by termites regardless of extraction process.[11] This phenomenon means that stimulants appear to be produced from the main components, including hemicellulose, of wood by steam treatment. The high-temperature drying processes obviously produced termite feeding stimulants and/or degraded original feeding deterrent such as flavonoids.[10]

In this experiment, both high-temperature-drying schedules used a presteaming process at 95°C for 8 h. This process possibly caused chemical changes in a portion of wood constituents because a quantity of acetate was generated in the wood–water mixture during a water extraction procedure at 80°C for 24 h to yield the flavonoids from larch wood sawdust.[12] The DTG analysis suggested the breakdown of hemicellulose after the high-temperature drying because the peak at about 310°C, which was attributed to hemicellulose,[6] decreased. When kiln-dried southern pine poles were autoclaved at 118°C for 0–20 h, the yield of hemicellulose decreased depending on the increasing steaming time.[13] Therefore, we should ensure the effect of the presteaming process to produce the feeding attractant to the termites in future studies.

Heating treatments including hydrothermolysis have recently been studied to obtain highly durable wood materials.[14–18] The main targets of these studies were to achieve "decay durability" without chemical treatment to eliminate environmental pollution because these studies were mainly carried out in EU countries where there is less or no infestation from termites. Although softwood species such as spruce, Scots pine and radiata pine that were tested in these experiments had different constituents from Japanese larch, it is estimated that termite-feeding stimulants will be precisely generated, from the results of our experiment.[1] In particular, one-step heat treatments of wood without curing processes under dry conditions may yield feeding stimulants, and the generated stimulants are likely to remain in the wood. Much attention to termite durability as well as decay durability are required when heat-treated wood materials are used for buildings and exterior constructions etc. in termite-infested areas such as Japan, Australasia, east-coast USA, and southern EU countries.

Acknowledgments The authors thank Dr. T. Yoshida, Nagano Prefectural Forestry Research Centre, Nagano, Japan, for providing tested timbers and valuable comments.

References

1. Doi S, Kurimoto Y, Ohmura W, Ohara S, Aoyama M, Yoshimura T (1999) Effects of heat treatments of wood on the feeding behaviour of two subterranean termites. Holzforschung 53:225–227
2. Doi S, Takahashi M, Yoshimura T, Kubota M, Adachi A (1998) Attraction of steamed Japanese larch (*Larix leptolepis* (Sieb et Zucc.) Gord.) heartwood to a subterranean termite *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae). Holzforschung 52:7–12
3. Ohmura W, Doi S, Aoyama M, Ohara S (1999) Components of steamed and non-steamed Japanese larch (*Larix leptolepis* (Sieb et Zucc.) heartwood affecting the feeding behaviour of the subterranean termite *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae). Holzforschung 53:569–574
4. Kurisaki H, Tsukamoto H, Mizumoto K (2001) Durability of sugi (*Cryptomeria japonica* D. Don) heartwood dried at high temperature against the brown rot fungus *Fomitopsis palustris* (in Japanese). Mokuzai Hozon 27:61–66
5. Anon (1994) Japanese Industrial Standard "Methods of test for woods" JIS Z 2101:1994. Approved by Japanese Industrial Standard Committee
6. Soltes E, Elder T (1981) Pylolysis reactions. In: Raton B (ed) Organic chemicals from biomass. CRC Press, FL, USA, pp 82–87
7. Sehlstedt-Persson SMB (1995) High-temperature drying of Scots pine. A comparison between HT- and LT-drying. Holz Roh Werkst 53:95–99
8. Kubinsky E, Geza I (1973) Influence of steaming on the properties of red oak Part I. structural and chemical changes. Wood Sci 6:87–94
9. Yoshida T, Hashizume T, Fujimoto N (2000) High-temperature drying characteristics on boxed-heart square timber of karamatsu and sugi (in Japanese). Mokuzai Kogyo 55:357–362
10. Ohmura W, Doi S, Aoyama M, Ohara S (2000) Antifeedant activity of flavonoids and related compounds against the subterranean termite *Coptotermes formosanus* Shiraki. J Wood Sci 46:149–153
11. Doi S, Shibutani S, Ohmura W, Takiuchi H (2002) Evaluation of steamed Japanese larch sapwood as a bait of termite (in Japanese). In: Abstracts of the 52nd Annual Meeting of the Japanese Wood Research Society. April 2–4, 2002, Gifu, Japan, p 627
12. Chen K, Aoyama M, Ohmura W, Ohara S, Doi S (2000) Water extraction system of flavonoids to use their termite antifeedant potential. In: Proceedings of International Symposium on Cellulose and Lignocellulosics Chemistry 2000. December16–18, 2000, Kunming, China, pp 237–240
13. Thompson WS (1969) Effect of steaming and kiln drying on the properties of southern pine poles. Part II: chemical properties. Forest Prod J 19:37–43
14. Dirol D, Guyonnet R (1993) The improvement of wood durability by retification process. International Research Group on Wood Preservation IRG/WP/93-40015
15. Viitanen H, Jämsä S, Paaianen L, Nurmi A, Viitaniemi P (1994) The effect of heat treatment on the properties of spruce. A preliminary report. International Research Group on Wood Preservation IRG/WP/94-40032
16. Tjeerdsma BF, Boonstra A, Militz H, (1998) Thermal modification of non-durable wood species 2. Improved wood properties of thermally treated wood. International Research Group on Wood Preservation IRG/WP/98-40124
17. Tjeerdsma BF, Stevens M, Militz H (2000) Durability aspects of (hydro) thermal treated wood. International Research Group on Wood Preservation IRG/WP/00-40160
18. Syrjanen T, Kangas E (2000) Heat treated timber in Finland. International Research Group on Wood Preservation IRG/WP/00-40158