WOOD RESEARCH
60 (6): 2015
873-880

ENHANCED TERMITE RESISTANCE OF SCOTS PINE (*PINUS SYLVESTRIS* L.) SOLID WOOD BY PHENOL-FORMALDEHYDE TREATMENT

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(Received June 2015)

ABSTRACT

In order to assess the resistance of phenol-formaldehyde (PF) modified wood to subterranean termites (*Reticulitermes flavipes*), laboratory no-choice tests following the standard EN 117 (2013) were performed for 8 weeks. Scots pine (*Pinus sylvestris* L.) sapwood specimens were modified with low molecular weight PF-resin in two concentrations. After vacuum-pressure impregnation and curing, the wood specimens were subjected to an accelerated aging test according to the standard EN 84 (1997). Five replicates per each concentration group were exposed to termites as well as unmodified wood. Following exposure, the specimens were evaluated for termite damage using a visual rating system and mass losses were also recorded. All treated samples showed higher resistance to termites than the controls. After testing period, 100 % termite mortality was found for modified wood. PF-resin treatment significantly reduced the feeding activity of termites and the mass losses caused.

KEYWORDS: Phenol-formaldehyde, wood modification, termite resistance, *Reticulitermes flavipes*, visual evaluation, mass loss.

INTRODUCTION

Wood-based materials resistant to moisture and biological attack would have potential outdoor applications under severe environmental conditions in areas where diverse fungi or

termites might attack the product. Due to environmental concerns and associated regulations, there is a pressure on the wood industry to find alternative methods to preserve wood without using biocides. During the last decades, new wood modification techniques have been widely investigated resulting in improvements in dimensional stability, durability and weathering resistance (Hill 2006). More specific, some studies reported the effectiveness of several wood modification treatments against termite attack. For example, wood modified with dimethyloldihydroxy-ethyleneurea (DMDHEU) (Militz et al. 2011, Gascón-Garrido et al. 2013), acetylation (Imamura and Nishimoto 1986, Ibach et al. 2000, Westin et al. 2004), furfurylation (Hadi et al. 2005, Lande et al. 2006), quat- and amino-silicone emulsions (Ghosh et al. 2012), short-chain siloxane emulsions (Gascón-Garrido et al. 2015), wax impregnation (Scholz et al. 2010) and thermo-treatment (Oliver-Villanueva et al. 2013) have been shown to improve wood resistance to damage by termites. In contrast, some of the treatments only imparted minor protection or even decreased the natural resistance (Rowell 2006, 2007, Militz et al. 2009, 2011). Level of modification, selection of wood species, treatment procedure, test methods followed and termite species might influence the results.

Impregnation of wood with phenol-formaldehyde (PF) resin has been studied since the 1930s to increase mechanical strength and dimensional stability, resulting in the introduction of "Impreg" and "Compreg" as first PF impregnated wood composites to be commercially manufactured (Stamm and Seborg 1936, Rowell and Banks 1985). Water is used as the solvent for water-soluble PF resins, which reduces the costs of PF resins, provides readily available raw materials, simple production process and equipment, but is also non-toxic and difficult to ignite (Huang et al. 2014). Low molecular weight resin interacts with the hydroxyl groups of wood constituents and as a result new hydrogen bonds are established (Ryu et al. 1993). The effectiveness of this interaction depends on the penetration of the PF resin into wood cell walls. Only low molecular weight resins can easily penetrate and play a role in dimensional stability and decay resistance, while resins with higher molecular weight will mainly occupy the lumen (Furuno et al. 2004, Klüppel and Mai 2013). The distribution of low molecular weight PF resin has been observed by various microscopic techniques (Inoue et al. 1993, Wan and Kim 2008, Biziks et al. 2015).

PF resins have been reported to improve mechanical properties (Chong et al. 2010, Hoong et al. 2013, Huang et al. 2013) and dimensional stability (Deka and Saikia 2000, Gabrielli and Kamke 2010, Klüppel and Mai 2013). PF treatment has also been shown to enhance the resistance to decay fungi (Ryu et al. 1991, Furuno et al. 2004, Nur Izreen et al. 2011). A number of studies report on the increased termite resistance of wood due to the PF treatment. PF treated Japanese cedar, western hemlock and Japanese beech performed well against Coptotermes formosanus in a laboratory "wood block test" and the feeding activity declined severely (Takahashi and Imamura 1990). Ryu et al. (1993) studied the effects of PF-resin treatment on termite resistance in relation to molecular weights. Also PF resin-treated particleboards of Japanese cedar showed resistance to *C. formosanus* in a laboratory "wood block test" (Kajita and Imamura 1991), results which were in agreement with the test performed with PF resin-treated particleboards made of albizzia, rubber wood, radiata pine and Japanese cedar against *C. formosanus* (Yusuf et al. 1999). Indian softwood *Anthocephanlus cadamba* Miq. treated with PF resin showed resistance to *Odontotermes* spp. after 6 months exposure in a field test (Deka and Saikia 2000). Treatment with low molecular weight PF resin was able to enhance the resistance of oil palm veneers (Loh et al. 2011) and blocks (Bakar et al. 2013) to *Coptotermes curvignathus*.

The aim of this study was to determine the performance of PF modified Scots pine wood against *Reticulitermes flavipes*, the most common termite found in North America which was also introduced in Europe (Kollar 1837).

MATERIAL AND METHODS

Materials

Tests specimens with size of 25 x 15 x 50 mm (R x T x L) were prepared from sapwood of Scots pine (*Pinus sylvestris* L.) straight grained and free of knots and visible cracks. Before impregnation, wood specimens were conditioned in a climate chamber for two weeks at 20°C and 65 % relative humidity (RH) until they reached equilibrium moisture content of approximately 12 %. Five replicates were used per treatment concentration. Untreated Scots pine sapwood specimens served as controls to check the virulence of the termites taken for the test.

PF resin treatment

Low molecular weight phenol-formaldehyde (PF) resin was supplied by Momentive Performance Materials Inc. (Stanlow, United Kingdom). PF resin was diluted with distilled water and sodium hydroxide to adjust the treatment concentration. Two aqueous resin solutions were prepared: 10 and 20 % based on the solid content of PF. The treatment process was conducted in a stainless steel vessel involving vacuum at 10 kPa (1 h) and pressure at 600 kPa (2 h). The solution uptake (with mass of specimens before and after impregnation) was 160 %, equivalent to PF-resin retention of 16 and 32 % for PF 10 and PF 20 %, respectively. Subsequently, the specimens were gradually cured in four steps (24 h each) at 30, 60, 80 and 103°C. After curing, wood specimens were conditioned at 20°C and 65 % RH until they reached equilibrium moisture content.

Accelerated aging

Prior to termite testing, the wood specimens were subjected to an accelerated aging test (leaching procedure) according to the standard EN 84 (1997) in order to remove unfixed chemicals. The specimens were submerged into distilled water (in the proportion of one volume of wood to five volumes of water) using 4-kPa vacuum for 20 min and kept submerged over a period of 14 days. Within this period the water was changed nine times on alternate days. After the completion of the accelerated aging and prior to the exposure to termites, wood specimens were conditioned at 20°C and 65 % RH until they reached constant mass.

Termite test

The no-choice test was conducted to evaluate the resistance of PF treated wood in a force-feed environment according to the standard EN 117 (2013). Workers, soldiers and nymphs of *Reticulitermes flavipes* (Kollar) were collected from Saint Trojan forest, Oleron island (region of Bordeaux). Test containers were prepared with moistened sand in the proportions of one volume of water to four volumes of sand. A small piece of original culture wood (0.5 g) was added to the sand according to the standard. A ring glass was placed on a vertical wall of the container to avoid the direct contact between the sand and the wood specimen. A group of 250 worker termites and a proportional percentage of soldiers and nymphs (1-5 %) were distributed carefully in each test container. After that, the test containers were placed in the testing chamber at 26 ± 2°C and 70 ± 5 % RH. Over a period of two to four days after setting up the colonies, the termite activity of each test container was observed and those that did not show a proper establishment of the termite population were rejected. Five replicates per group were exposed to termites. During the exposure time of 8 weeks, weekly observations were carried out to assure the appropriate substrate moisture and to monitor the presence of termites and their activity. After the exposure, the evaluation was done using a visual rating system according to EN 117 (2013) and subsequently classified according to prEN 350 (2014). Additionally, mass losses were also recorded.

RESULTS AND DISCUSSION

Test validation

According to EN 117 (2013), the test is valid if the untreated virulence control specimens correspond to level 4 when visually examined and have at least 50 % of worker survivors. The level of attack for the virulence control specimens was 4 and the average survival rate was 52 % (Tab. 1). Therefore, the test is validated.

Classification of wood durability according to visual examination

PF-resin treated Scots pine was resistant to termites in laboratory tests (Tab. 1). Although the complete inhibition of termite attack was not accomplished by PF treatment, the feeding activity of termites on treated wood was significantly reduced. The mortalities of termites exposed to PF-resin treated wood increased gradually and reached 100 % after 5 weeks for PF 10 and after 4 weeks for PF 20 %. This suggests that the high mortality rate was not due to termicidal chemical components, but to the inability to digest the material. This is in agreement with other studies, which reported that PF treatment causes inability to digest the material and non-palatability of the wood (Takahashi and Imamura 1990, Kajita and Imamura 1991, Ryu et al. 1993, Bakar et al. 2013). Results suggest that there are no big differences by increasing the PF-resin concentration, and PF 10 % is sufficient to impart resistance to termites. The only difference is that 100 % termite mortalities are one week shortened for PF 20 %. Wood specimens were examined and visually rated according to EN 117 (2013), and the durability class was assigned according to the criteria of prEN 350 (2014) (Tab. 1). Although two PF-treatment concentrations (10 and 20 %) obtained the same mean rating (1.8), they were classified as resistant and moderately resistant, respectively.

Tab. 1: Classification after 8 weeks exposure to R. flavipes.

Treatment	Survival rate (%) (mean values ± standard deviation)	Visual rating (mean values and relative rating)[a]	Durability class[b]
PF 10 %	0.0 ± 0.0	1.8 (20 % "1" and 80 % "2")	Resistant
PF 20 %	0.0 ± 0.0	1.8 (40 % "1", 40 % "2" and 20 % "3")	Moderately resistant
Untreated	52.0 ± 0.6	4.0 (100 % "4")	Not resistant

[a]Visual rating according to EN 117 (2013)

[b]Wood durability classification system according to prEN 350 (2014): 0 = No attack; 1 = Attempt to attack; 2 = Light attack; 3 = Medium attack; 4 = Heavy attack. Resistant = ≥ 90 % "0, 1" and max 10 % "2"; Moderately resistant = < 50 % "3, 4"; Not resistant = ≥ 50 % "3, 4".

Analysis of mass loss caused by termite attack

In terms of mass loss, there was a significant effect of PF-resin treatment on the susceptibility of Scots pine. Despite the fact that the complete inhibition of wood consumption has not reached yet, all PF-resin treated specimens exhibited much lower mass losses than untreated specimens (Tab. 2). PF 10 % treated Scots pine resulted in mean mass loss of 0.5 %, while specimens treated with PF 20 % presented similar mean mass loss of 0.1 % (Tab. 2). In contrast, mean mass loss of untreated Scots pine was 7.5 %. Previous studies have been reported that PF-resin treatment was effective in reducing mass loss of wood blocks and particleboards (Takahashi and Imamura 1990, Kajita and Imamura 1991, Loh et al. 2011, Bakar et al. 2013) and mass loss decrease slightly by increasing the PF concentration (Ryu et al. 1993).

Tab. 2: Mass loss after 8 weeks exposure to R. flavipes.

Treatment	Mass loss (%) (mean values ± standard deviation)
PF 10 %	0.5 ± 0.1
PF 20 %	0.1 ± 0.1
Untreated	7.6 ± 1.3

CONCLUSIONS

PF-resin treatment of Scots pine significantly reduces the feeding activity of termites during exposure to subterranean termites in a no-choice laboratory test. After 8-week testing period, termite mortality was 100 % for modified wood. Both PF-treatment concentrations (10 and 20 %) obtained the same mean rate in visual evaluation; however, they were classified as resistant and moderately resistant, respectively. In terms of mass loss, all treated samples showed much lower mass losses that untreated specimens.

ACKNOWLEDGMENT

The authors would like to thank Momentive Performance Materials Inc. for financial support.

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