International Biodeterioration &. Biodegradation 63 (2009) 548-552

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

journal homepage: www.elsevier.com/locate/ibiod

Decay and termite resistance, water absorption and swelling of thermally compressed wood panels

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A R T I C L E I N F O

Article history:
Received 31 December 2008
Received in revised form
23 February 2009
Accepted 24 February 2009
Available Online 23 April 2009

Keywords:
Thermal compression
Decay resistance
Termite resistance
Dimensional stability
Solid wood panels

A B S T R A C T

This study evaluated decay and termite resistance of thermally compressed pine wood panels under pressure at either 5 or 7 MPa and either 120 or 150 °C for 1 h. Wood specimens from the panels were exposed to laboratory decay resistance tests by using the wood degrading fungi, *Gloeophyllum trabeum* and *Trametes versicolor.* The thermal compression process caused increases in density and decreases in thickness of the panels: however, laboratory decay resistance tests revealed that thermally compressed wood was not resistant against the wood degrading fungi tested. More interesting results were found in laboratory termite resistance tests by using the Eastern subterranean termites, *Reticulitermes flavipes.* As pressure and temperature applied to the specimens increased to 7 MPa and 120 °C, mass losses in the specimens gradually decreased in comparison with control specimens. However, the specimens compressed at 7 MPa and 150 °C showed higher mass losses when compared to the specimens compressed at 7 MPa and 120 °C. The lowest water absorption and swelling rates were seen in the specimens exposed to a pressure of 7 MPa at 120 °C. The thermal compression process at 7 MPa and 150 °C resulted in the highest water absorption and swelling in the specimens.

1. Introduction

As a result of a number of chemical reactions or modifications in wood cell components during thermal processing, wood can be modified and dimensional stability, hygroscopicity. and biological resistance of wood can be improved (Kamdem et al., 2002). Several studies have shown that thermal modification increases the biological resistance of wood against wood degrading fungi; however, several others have stated that heat-modified wood is not suitable for ground contact applications (Jämsä and Viitaniemi, 1998; Tjeerdsma et al., 1998; Kamdem et al., 1999; Wienhaus, 1999; Rapp et al., 2000; Kamdem et al., 2002; Tjeerdsma et al., 2002; Weiland and Guyonnet. 2003; Doi et al., 2004; Welzbacher and Rapp. 2005; Kartal, 2006; Boonstra et al., 2007). Hakkou et al. (2006) have recently stated that decay resistance of heat-modified wood is questionable according to the literature and needs further detailed investigations. The increase in decay resistance by thermal processes is generally explained by various hypotheses: low affinity of heat-treated wood to water; formation of toxic compounds which act as biocides; chemical modification of main wood components and breakdown of hemicelluloses (Weiland and Guyonnet. 2003; Hakkou et al., 2006; Del Menezzi et al., 2008). Hill (2006) also reported that the loss of OH groups from the cell wall components affects the ability of fungal enzymes to metabolize the wood substrate.

In the presence of heat, the objective of wood compression is to increase its physical and mechanical properties and this process might be result in a new material depending on process conditions. Thermally compressed wood without resin is known as *Staypak,* while compressed wood with phenol formaldehyde resin treatment is called *Compreg* (Wood Handbook, 1999; Ibach and Ellis, 2005). In the United States, studies on densifying wood date back to 1900s. The compression of solid wood has been done in Germany since 1930 under the trade name of *Lignostone.* Laminated compressed wood has been made under the trade name *Lignofol.* Compressed wood products from wood species with low density were produced in 1980s specifically for utilization of some fast growing tree species (Norimoto, 1993; Norimoto, 1994; Wang et al., 2000). Similar materials such as *Jicwood* and *Jablo* have been in production in England (Rowell and Konkol, 1987).

Compression in wood is generally considered to be analogous to hot pressing wood composites panels with the exception that it takes longer to obtain solid wood compression set without the

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0964-8305/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ibiod.2009.02.001

bonding effect of resins (Wang and Cooper, 2005a,b). The thermal compression process could also affect drying speed, equilibrium moisture content (EMC), hygroscopicity. dimensional stability. durability. surface quality, modulus of rupture, modulus of elasticity, Janka hardness, surface abrasion strength, nail/screw withdrawal strength, and shear modulus of wood (Tabarsa, 1995; Navi and Girardet, 2000; Kubojima et al., 2003; Blomberg et al., 2005; Wang and Cooper, 2005a; Unsal and Candan, 2007; Yoshihara and Tsunematsu, 2007; Welzbacher et al., 2008). In this study, decay and termite resistance of solid wood panels after heat-compression under various temperatures and pressures was evaluated. The specimens from compressed solid panels were subjected to laboratory decay and termite resistance tests. Water absorption and swelling in the specimens were also studied in comparison with control specimens. Traditional heat modification procedures are applied to wood without pressing. Our previous attempts showed that the higher temperatures than 150 °C. the more deformation occurred in the panels after modification due to compression. Because of these reasons, the maximum temperature was set as 150 °C. One of the aims in the study is to use lower temperatures than those used in commercial applications.

2. Materials and methods

2.1. Hot pressing procedure

Wood specimens used in the study were obtained from Scotch pine (*Pinus sylvestris* L.) solid panels with dimensions of 250 by 500 by 18 mm. The solid panels were first hot-pressed by using a laboratory hot press at a temperature of either 120 °C or 150 °C and press pressure of either 5 or 7 MPa (≅725 or 1015 lb/in^2) for 60 min (Table 1). A diagram of the process applied to wood panels is also given in Fig. 1.

2.2. Decay test

Decay resistance was tested by exposing specimens (20 by 20 by panel thickness) cut from the panels to either *Cloeophyllum trabeum* MAD 617 or *Trametes versicolor* MAD 697 in a soil block test for 12 weeks according to AWPA E10-06 standard method (AWPA. 2007a). After 12 weeks of incubation at 27 °C and 70 per cent relative humidity (RH), the surface fungus mycelium was removed, the specimens were dried at 60 °C. and weight losses were determined as percentage of total specimen mass. Nine specimens were tested for each fungus and treatment group. The per cent mass loss in the specimens provided a measure of the relative decay susceptibility or, inversely, of decay resistance of the sampled material.

2.3. Termite test

A no-choice termite resistance test with *Reticulitermes flavipes* Kollar (Eastern subterranean termites) was performed using five test specimens (20 by 20 by panel thickness) for each treatment group. One specimen was placed in a glass container with moist sand and one gram of *R. flavipes*. The containers were maintained at 25 "C and 80 per cent RH for 4 weeks based on a modified AWPA E1-06 standard method (AWPA. 2007b). At the end of the test, specimens were oven dried and reweighed to determine mass loss. Termite mortality occurring at the end of the 4-week-exposure period was also recorded.

Table 1
Process parameters

Treatment group	Pressure (MPa)	Temperature (°C)	Time (min)
1	5	120	60
2	5	150	60
3	7	120	60
4	7	150	60
Control	–	–	–

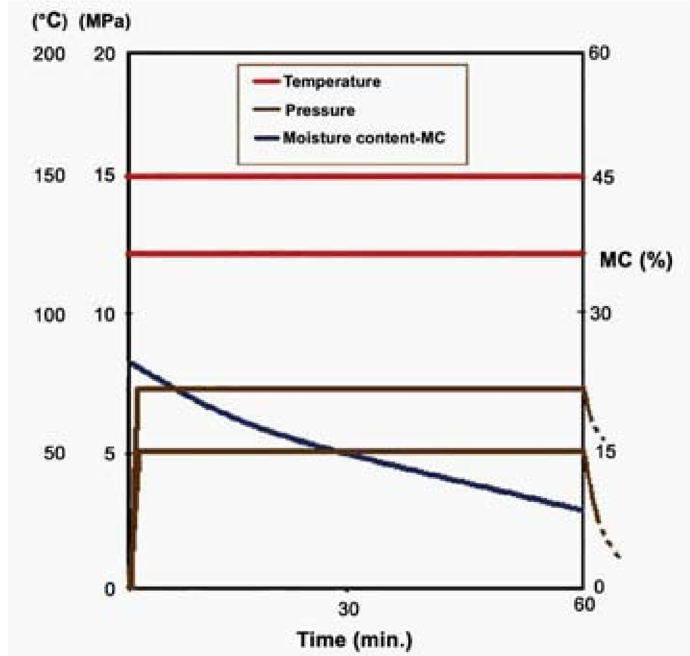

Fig. 1. Scheme of the thermal press process.

2.4. Swelling and water absorption tests

Swelling and water absorption tests were performed eight weeks after the specimens were stored in a conditioning room to eliminate the recovery of compression deformation in thermally compressed specimens. Radial and tangential swellings were determined by measuring oven-dry and wet dimensions of the specimens (50 mm by 50 mm by panel thickness) in radial and tangential direction by using the below equation:

$$\text{Radial or tangential swelling (\%)}: \left[\frac{(L_1 - L_0)}{(L_0)}\right] \times 100$$

where,

L_1: Wet (radial or tangential) dimension after immersion in water for 24h (mm).
L_0: Oven-dry (radial or tangential) dimension (mm).

Water absorption (WA) was evaluated according to the below equation:

$$WA\ (\%) = \left[\frac{(W_2 - W_1)}{W_1}\right] \times 100$$

where,

W_2: Weight after immersion in water for 24 h (g).
W_1: Oven-dry weight before immersion in water (g).

2.5. Vertical density profile

The vertical density profile (VDP) of the thermally compressed and untreated control specimens was determined by using an X-ray density profiler (GreCon Measurement Systems, Germany) at Quality Control Laboratories of Kastamonu Integrated Wood Industry and Trade Inc., Kocaeli, Turkey.

3. Results and discussion

When compared to control specimens, surfaces of the compressed panels were darkened due to heat applied during the process. The decrease in the thickness of the specimens exposed to thermal compressing at a pressure of 7 MPa at 150 °C was more distinct in comparison with controls and specimens from other treatment groups. Table 2 shows density values and decreases in the thickness of the panel specimens. When compared to control specimens, there were slight increases in density values of the specimens of Group 1 and 2; however, density of Group 4 specimens increased nearly 80 per cent after thermal compression. Decreases in the thickness appeared to be in good accordance with increases in density values of the panel specimens after the process. Considerable decreases were seen in the specimens subjected to thermal compressing at a pressure of 7 MPa at 150 "C.

3.1. Decay resistance

The specimens subjected to thermal compression showed higher mass losses after 12-week decay resistance tests against the brown-rot fungus, *G. trabeum* in comparison with control specimens (Fig. 2). The mass losses in thermally compressed specimens were around 60 per cent; however, control specimens had mass loss of about 40 per cent. In decay resistance tests using the white-rot fungus, *T. versicolor,* thermal compressing resulted in mass losses of nearly 35 per cent in the specimens (Fig. 3). Mass losses for control specimens were not significantly different from the thermally compressed specimens. These results suggest that thermal compressing process used in this study did not provide any protection against the fungi tested in laboratory conditions.

3.2. Termite resistance

There were no statistically important differences between the mass losses in control and Group 1 specimens exposed to laboratory termite resistance tests for 4 weeks (Fig. 4). However, Group 2, 3 and 4 specimens showed considerably lower mass losses in comparison with control and Group 1 specimens. Unexpectedly, mass losses increased in Group 3 specimens and mass losses in these specimens were as high as in Group 2 specimens. Termite mortalities in Group 3 specimens which showed the lowest mass losses and in Group 4 specimens reached 20 per cent and 10 per cent, respectively; however, no dead termites were seen in control and other groups (Fig. 4).

Table 2
Density and changer in thickness of panels during thermal compressing.

Treatment group	Density (g/cm³)	Decrease in thickness (%)[a]
1	0.47	3.3
2	0.58	4.7
3	0.66	7.2
4	0.83	38.8
Control	0.46	–

[a] Bared on control specimens

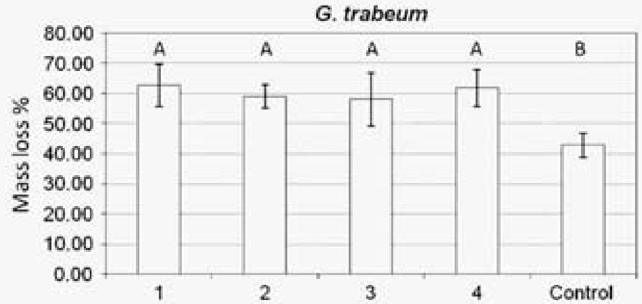

Fig. 2. Mass losses in the specimens exposed to *G. trabeum* for 12 weeks (the same letters over each bar indicate that there is no statistical difference between specimens according to Duncan's multiple range test ($p < 0.05$)). *X*-axis shows treatment groups.

Doi et al. (2004) found no increased durability of heat-treated wood based on PLATO treatments against wood degrading fungi, *Tyromyces palustris* (brown-rot fungus) and *T. versicolor* (white-rot fungus) in laboratory conditions. They also showed no increases when their specimens were subjected to termite resistance tests using *Reticulitermes speratus*. Doi et al. (2005) also showed that wood specimens exposed to high-temperature schedules (120–130 °C) were susceptible against *T. palushis* and attacks from termites *Coptotermes formosanus* and *R. speratus*. Kamdem et al. (2002) found that heat treatments did not sufficiently increase the decay resistance to use the heat-treated wood in ground contact. Tjeerdsma et al. (2002) found that the resistance of heat-treated wood by PLATO and dry-heat treatments was improved considerably against *Coniophora puteana* (brown-rot fungus) and *T. versicolor.* Welzbacher and Rapp (2005) evaluated various types of heat-treated materials and found that all heated wood showed significantly increased durability against decay in ground contact compared to untreated Scots pine sapwood however, the heat-modified materials were not durable after a 4-year test in ground contact. Kartal (2006) showed that mass losses of sugi sapwood specimens exposed to heat treatments at 180 °C for 2 and 4 h increased in decay resistance tests using *T. palushis;* however, mass losses in the specimens subjected to *T. versicolor* gradually decreased when compared to control specimens. Ibach and Ellis (2005) have stated that during compression with 1400–1600 lb/in² (≅ 10–11 MPa) pressure, with temperatures of 170–177°C. lignin flows relieving internal stresses, but also causing a darkening of the wood. The resultant wood product is more dimensionally stable, but not necessarily more biologically resistant. It has also been stated that thermally modified wood does not possess durability against marine borers (Westin et al., 2006) and in ground contact applications (Welzbacher and Rapp, 2007).

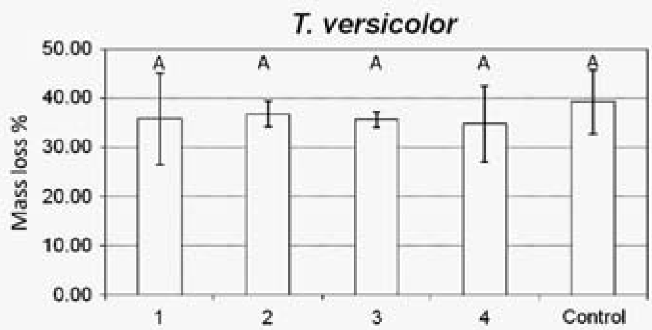

Fig. 3. Mass losses in the specimens exposed to *T. versicolor* for 12 weeks (the same letters over each bar indicate that there is no statistical difference between specimens according to Duncan's multiple range test ($p < 0.05$)). *X*-axis shows treatment groups.

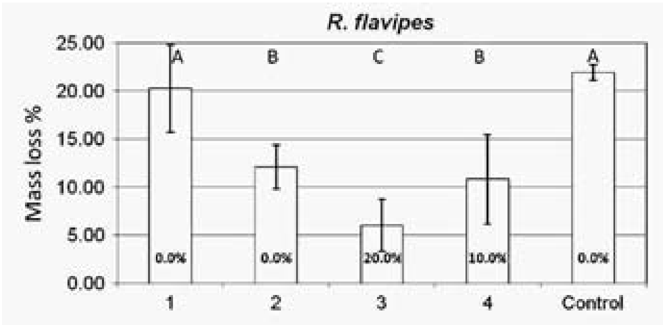

Fig. 4. Mass losses in the specimens exposed to *R. flavipes* for 12 weeks and termite mortalities (% values in the bars represent termite mortalities at the end of tests; the same letters over each bar indicate that there is no statistical difference between specimens according to Duncan's multiple range test ($p < 0.05$)). *X*-axis shows treatment groups.

3.3. Swelling and water absorption properties

Table 3 shows water absorption, radial and tangential swelling of the specimens after immersion for 24-h in water. The lowest water absorption and swelling were obtained for Group 3 specimens. Group 4 specimens had the highest water absorption and swelling. Overall, there were no big differences among radial swelling of the specimens. Kortelainen et al. (2006) has reported that heat treatments decreased the water absorption of spruce and pine heartwood specimens, even though pine sapwood specimens heat-treated at temperatures below 230 °C revealed higher water absorption. Hakkou et al. (2005) found that heat-treated wood specimens showed modifications of wood polysaccharide components leading to lower water absorption in wood. Boonstra and Tjeerdsma (2006) state that the availability and/or accessibility of the free hydroxyl groups of wood carbohydrates play an important role in the process of water adsorption. Depolymerization of the carbohydrates and especially the hemicelluloses in heat-treated wood results in a reduction of the total amount of hydroxyl groups, including the free hydroxyl groups. Hong (1984) found that as densification temperature and duration increased, but only at temperatures above 160 °C. moisture absorption and swelling decreased, and extension of duration and temperature resulted in a slight reduction of swelling.

3.4. *Vertical density profile*

The control samples had an average mean density (MD) of 460 kg/m³. Group 3 specimens showed peak density (PD) of 780 kg/m³. core density (CD) of 610 kg/m³. The group's MD was 660 kg/m³. Group 4 had the highest PD and CD values (900 kg/m³ and 800 kg/m³, respectively). The group's MD was calculated as 830 kg/m³. The vertical density profile (VDP) in the solid wood boards was closely related with the press pressure and temperature. Increasing pressure and temperature resulted in increased PD and MD values, which are defining factors of VDP. The results showed that as press pressure and temperature increased, radial swelling decreased compared with control specimens; however, when the pressing parameters were at maximum levels, radial swelling values were the highest. Because of densification on the surface layers of solid wood boards, swelling values were affected positively.

Table 3
Water absorption, radial swelling, and tangential swelling in the specimens.

Treatment group	water absorption (%)	Radial swelling (%)	Tangential swelling (%)
1	31.55	3.64	5.49
2	47.77	2.78	7.36
3	18.11	2.72	4.10
4	89.08	6.95	35.61
Control	54.73	5.98	6.86

4. Conclusions

No increases in biological resistance to decay fungi in thermally pressed wood specimens were observed during this study. However, two groups of specimens did show considerably lower mass losses in termite resistance tests when compared with control blocks. Arango et al. (2006)showed an inverse correlation between mass loss from termite feeding and specific gravity of tropical hardwood species. It is possible that compression of wood is increasing the specific gravity/density of the wood substrate. Conversely, Perdure heat treatment alone of Aspen showed no increase in resistance to termites (Environment Canada Innovation Technological Innovation Data Sheet, 2006). This may suggest that pressure, rather than heat has a more significant effect on termite resistance than heat alone. It may be concluded therefore, that resistance of thermally modified wood to biological agents may vary due to several factors, such as process temperature and time, types of organisms to which the wood is exposed, wood species, test conditions etc. Laboratory decay resistance tests may provide much more severe degradation conditions in comparison with above ground tests. Heat-modified wood is generally used in above ground applications where fungal attack is normally absent. Thus, above ground resistance tests may provide more realistic results. More detailed studies are needed to obtain a better understanding of the effect of thermal modification on the resistance of wood to decay.

The process conditions used in this study can be considered safe in terms of creating defects to the wood. In conventional drying methods, total drying time is in general 24 h for 20 mm thick pine solid panels (Unsal and Candan, 2008). However, in the process used in this study and our previous study (Unsal and Candan, 2007). drying time decreased to 1 h to achieve the same final moisture content (about 8 per cent). In this process, the board thickness decreased to 11 mm from 18 mm by using the maximum pressure. Although reduction in thickness was approximately 39 per cent, no drying defects were seen. In our previous study, the same thermal compressing process also improved final moisture content, density and Janka hardness of wood specimens when compared to control specimens (Unsal and Candan. 2007). Biological performance of such materials is still questionable even though density and hardness values are improved under thermal processing. However, new wood protection technologies with a low environmental impact to increase resistance of wood against biodeterioration could have significant advantages over chemical wood protection.

Acknowledgements

The present work was supported by the Research Fund of Istanbul University. Project No: YÖP-1758. The authors also would like to thank Miss. Ece Akbulut and Miss. Dilek Celik, former undergraduate students at Department of Forest Products Engineering, Faculty of Forestry, Istanbul University, for their assistance with swelling and water absorption testing.

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