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Section 4 **Processes and Properties**

Preliminary investigation of biological resistance, water absorption and swelling of thermally compressed pine wood panels

Öner Ünsal[1], S. Nami Kartal[1], Zeki Candan[1],
Rachel Arango[2], Carol A. Clausen[2], Frederick Green III[2]

[1]Forestry Faculty, Istanbul University
34473 Bahcekoy, Istanbul, Turkey

[2]USDA Forest Service Forest Products Service
Madison, WI 53726 USA

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IRG SECRETARIAT
Box 5609
SE-114 86 Stockholm
Sweden
www.irg-wp.com

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Öner Ünsal[1], S. Nami Kartal[2], Zeki Candan[3],

Rachel Arango[4], Carol A. Clausen[5], Frederick Green III[6]

[1]Forestry Faculty, Istanbul University 34473 Bahcekoy, Istanbul, Turkey, e-mail: onsal@istanbul.edu.tr

[2]Forestry Faculty, Istanbul University 34473 Bahcekoy, Istanbul, Turkey, e-mail: snkartal@istanbul.edu.tr

[3]Forestry Faculty, Istanbul University 34473 Bahcekoy, Istanbul, Turkey, e-mail: zekic@istanbul.edu.tr

[4]USDA Forest Service Forest Products Service Madison, WI 53726 USA, e-mail: rarango@fs.fed.us

[5]USDA Forest Service Forest Products Service Madison, WI 53726 USA, e-mail: cclausen@fs.fed.us

[6]USDA Forest Service Forest Products Service Madison, WI 53726 USA, e-mail: fgreen@fs.fed.us

ABSTRACT

Wood can be modified by compressive, thermal and chemical treatments. Compression of wood under thermal conditions is resulted in densification of wood. This study evaluated decay and termite resistance of thermally compressed pine wood panels at either 5 or 7 MPa and at either 120 or 150°C for one hour. The process caused increases in density and decreases in thickness of the panels; however, laboratory decay resistance tests using one brown rot fungus and one white rot fungus revealed that thermally compressed wood was not resistance against the fungi tested. More interesting results were found in laboratory termite resistance tests. As pressure and temperature increased up to 7 MPa and 120°C, mass losses in the specimens decreased gradually when compared to control specimens. However, the specimens compressed at 7MPa and 150°C showed higher mass losses in comparison with the specimens compressed at 7 MPa and 120°C. Decay and termite resistance of such materials is still controversial even though density is improved under thermal processing.

Keywords: Thermal compression, heat modification, decay resistance, termite resistance, swelling, water absorption

1. INTRODUCTION

Thermal modification is a well-known process to change the dimensional stability, hygroscopicity, and biological resistance of wood. These changes are result of the chemical modification of wood cell components (Kamdem *et al*. 2002). Several studies have showed that thermal modification increases the resistance of wood to wood degrading fungi; however, several others have stated that thermal-treated wood is not suitable particularly when it is used in ground contact (Jamsa and Viitaniemi 1998, Tjeerdsma *et al*. 1998, Kamdem *et al*. 1999a, Kamdem *et al*. 1999b, 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). Along with heat, the objective of compressing of wood is also to increase its physical and mechanical properties and this process is resulted 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 1900. 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 especially 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 an exception that it takes longer to obtain solid wood compression set without the bonding effect of resins (Wang and Cooper 2005a, b).

Thermal compressing treatment could affect drying speed, equilibrium moisture content (EMC), 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. The hygroscopicity of wood can be also affected by heat (Tabarsa 1995, Navi and Girardet 2000, Kubojima *et al*. 2003, Blomberg *et al*. 2005, Wang and Cooper 2005a, Ünsal and Candan 2007, Yoshihara and Tsunematsu 2007, Welzbacher *et al*. 2008). In this study, we evaluated decay and termite resistance of solid wood panels after heat-compression under various temperatures and pressures. The specimens from compressed panels were subjected to laboratory decay and termite resistance tests.

2. MATERIALS AND METHODS

Scotch pine (*Pinus sylvestris* L.) panels with dimensions of 250 by 500 by 18 mm were used. The panels were hot-pressed to compress the panels 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 specimens is also given in Fig. 1.

Table 1: Processing parameters

Group	**Pressure [MPa]**	**Temperature [°C]**	**Time [min]**
1	5	120	60
2	5	150	60
3	7	120	60
4	7	150	60
Control	-	-	-

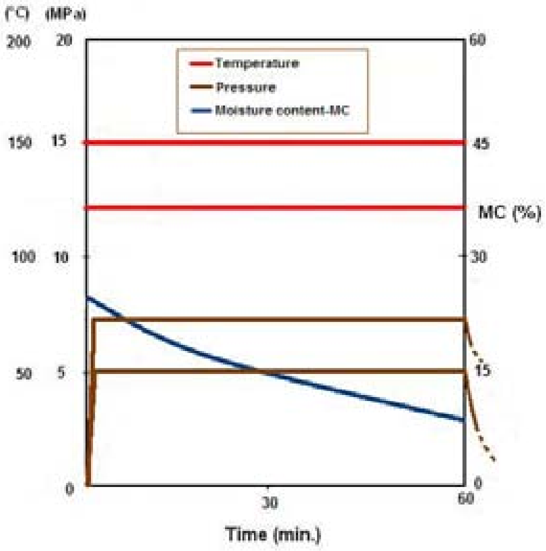

Figure 1. Scheme of the process followed in the study

Decay resistance test was determined by exposing the specimens (20 by 20 by 20 mm) from the panels to either G*loeophyllum trabeum* MAD 617 or *Trametes versicolor* MAD 697 in a soil block test for 12 weeks according to AWPA E10-06 standard method (AWPA 2007b) (Fig. 2). Nine specimens were tested for each fungus and group.

Figure 2. Laboratory decay resistance tests based on AWPA E10-06 standard method (AWPA 2007b)

No-choice termite resistance test with *Reticulotermes flavipes* Kollar (Eastern subterranean termites) was performed using five test specimens (20 by 20 by 20 mm) for each group. One specimen was placed in a glass container containing sand with one gram of *R. flavipes* (Fig. 3). The containers were maintained at 25°C and 80% RH (relative humidity) for 4 weeks based on slightly modified AWPA E1-06 standard method (AWPA 2007a). At the end of the test, specimens were oven dried and reweighed to determine mass loss. Termite mortality occurred at the end of 4-week-exposure period was also recorded.

Figure 3. Laboratory termite resistance tests based on AWPA E1-06 standard method (AWPA 2007a)

Radial and tangential swelling was determined by measuring oven-dry and wet dimensions of the specimens in radial and tangential direction by using the below equation:

Radial or tangential swelling (%): $[(L_1-L_0)/(L_0)]*100$

Where,

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

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

WA (%) = $[(W_2-W_1)/W_1]*100$

Where,

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

3. RESULTS AND DISCUSSION

Fig. 4 shows the appearance of experimental panels before and after hot-pressing. When compared to control specimens, surfaces of thermally compressed panel specimens were darkened due to heat applied during process. Decrease in the thickness of the specimens exposed to thermal compressing at a pressure of 7 MPa at 150°C was much more distinctive in comparison with control and other groups' specimens.

Figure 4. The appearance of the panels subjected to thermal compressing

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% after thermal compression. Decreases in the thickness appeared to be in good accordance with increases in density values of the panel specimens after thermal compression. Considerable decreases were seen in the specimens subjected to thermal compressing at a pressure of 7 MPa at 150°C.

Table 2: Density of percentage changes in thickness of panels during pressing

Group	Density [g/cm^3]	Decrease in thickness [%]*
1	0.47	3.3
2	0.58	4.7
3	0.66	7.2
4	0.83	38.8
Control	0.46	-

** based on control specimens*

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. 5). The mass losses in thermally compressed specimens were around 60%; however, control specimens had mass loss of about 40%. In decay resistance tests using the white rot fungus, *T. versicolor*, thermal compressing is resulted in mass losses of nearly 35% in the specimens (Fig. 6). Control specimens in this test had slightly higher mass losses when compared to thermally compressed specimens. These results suggest that thermal compressing process used in this study did not provide complete protection against the fungi tested in laboratory conditions.

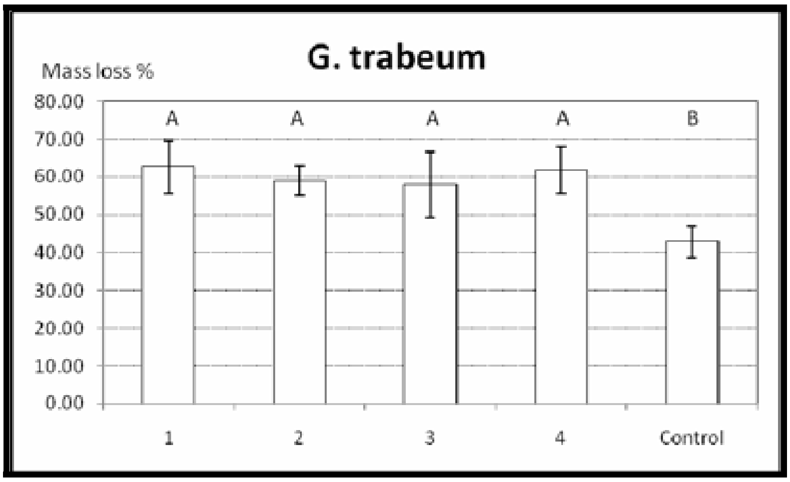

Figure 5. Mass losses in the specimens exposed to *G. trabeum* for 12 weeks (the same letters over each bar indicates that there is no statistical difference between specimens according to Duncan's multiple range test ($p \leq 0.05$))

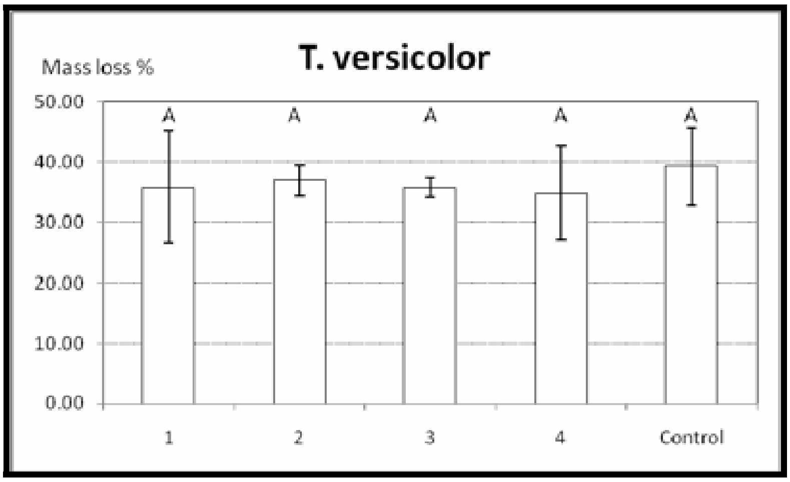

Figure 6. Mass losses in the specimens exposed to *T. versicolor* for 12 weeks (the same letters over each bar indicates that there is no statistical difference between specimens according to Duncan's multiple range test ($p \leq 0.05$))

There was no statistically important difference between the mass losses in control and Group 1 specimens exposed to laboratory termite resistance tests for 4 weeks (Fig. 7). However, Group 2 and 3 specimens showed considerably lower mass losses when compared to control and Group 1 specimens. Unexpectedly, mass losses increased in Group 3 specimens reaching as much values as Group 2 specimens. Termite mortalities in Group 3 specimens which showed the lowest mass losses and in Group 4 specimens reached 20% and 10%, respectively; however, no dead termites were seen in control and other groups (Fig. 7).

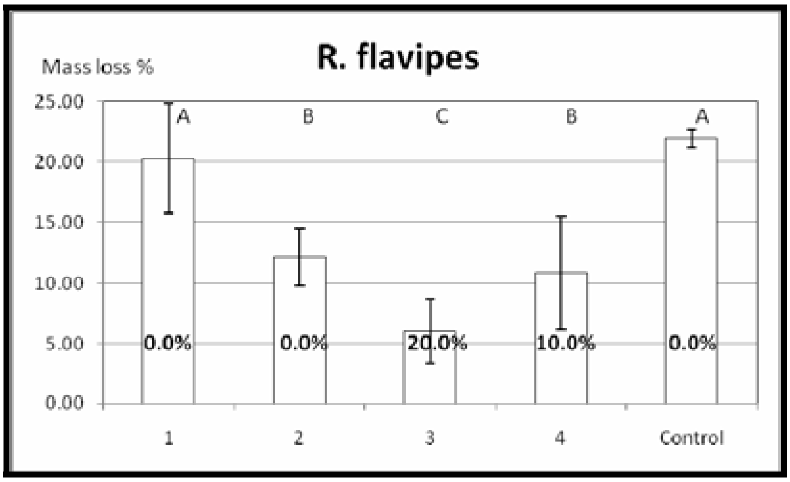

Figure 7. Mass losses in the specimens exposed to *R. flavipes* for 12 weeks and termite mortalities (% values represent termite mortalities at the end of tests; the same letters over each bar indicates that there is no statistical difference between specimens according to Duncan's multiple range test ($p \leq 0.05$))

Doi *et al*. (2004) found no increased durability of heat-treated wood based on PLATO treatments against wood degrading fungi, *Tyromyces palustris* and *Trametes versicolor* in laboratory conditions. They also showed no increases when their specimens were subjected to termite resistance tests using *Reticulitermes 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* 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 the sugi sapwood specimens exposed to heat treatments at 180°C for 2 and 4 h increased in decay resistance tests using *T. palustris*; 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/in^2 (≅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.

Fig. 8 shows percentage 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) showed that heat treatments decreased the water absorption of spruce and pine heartwood specimens, though pine sapwood specimens heat-treated at temperatures below 230ºC revealed higher water absorption. Hakkou *et al*. (2005) found that heat-treated wood specimens showed modifications of wood polysaccharide components leading to lower wettebality of 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 at temperatures above 160°C only, moisture absorption and swelling decreased, and extension of duration and temperature resulted in a slight reduction of maximum swelling.

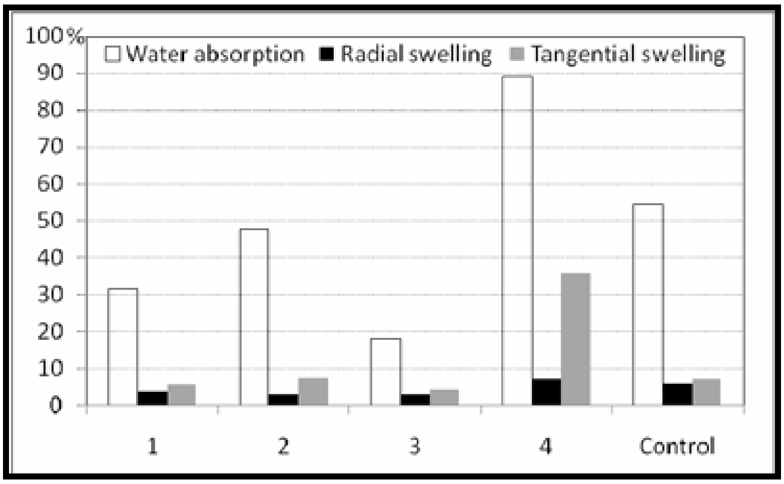

Figure 8. Percentage water absorption, radial and tangential swelling in the specimens after immersion for 24-h in water

4. CONCLUSIONS

Biological resistance of thermally pressed wood specimens did not increase. It may be concluded that the resistance of thermally-modified wood 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. Decay resistance test is also an important factor suggesting that laboratory tests may provide much severer 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 can provide more realistic results.

The process used in this study can be considered safe in terms of defects to be occurred in wood. Previous studies showed that in conventional drying methods, total drying time is in general 24 hours for 20 mm thick pine lumber when the moisture content is decreased from 19% to 8.6% (Ünsal and Candan, submitted). However in the process in this study, drying time decreased to 1 hour for the same moisture content. In this process, the board thickness decreased to 11 mm from 18 mm by using the maximum pressure. Although the thickness reduction was approximately 39%, no drying defects occurred. The same thermal compressing process also improved final moisture content, density and Janka hardness of wood specimens when compared to control specimens (Ünsal and Candan 2007). Biological performance of such materials is still questionable even though density and hardness values are improved under thermal processing.

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