CWPA Proceedings, 2009, 296-305

IMPACT OF BIOTHERMAL TREATMENT OF BALSAM FIR WOOD ON DURABILITY

Abdelkader Chaala[1] and Ahmed Koubaa[2]
[1] SEREX, 25, rue Armand-Sinclair, porte 5, Amqui (Québec) G5J 1K3
[2] Université du Québec en Abitibi-Témiscamingue, 445 Boul. de l'université, Rouyn-Noranda, (Québec) J9X5E4

Summary

Commercial bioesters were used as a heat vector to thermally treat balsam fir wood samples. Treatment temperature and time ranged from 150 °C to 200 °C and from 20 to 30 minutes, respectively. Treatment effects on wood durability, dimensional stability and bending strength were evaluated according to ASTM standard procedures. Results indicate that the treatment improved dimensional stability and mould resistance but had no significant impact on decay resistance. Bending properties decreased with increased treatment temperature and time.

1. Introduction

Wood is thermally or chemically treated to improve its durability in terms of resistance to biological attacks by fungi and insects, dimensional stability, weathering and degradation (Kamdem et al., 2002; Hakkou, et al. 2006; Esteves and Pereira, 2009). Thermal treatments for wood preservation are gaining popularity, mainly due to the development of new legislations against the use of classical preservation methods based on toxicity mechanisms (Esteves and Pereira 2009). These preservatives are perceived negatively by the general public because of their toxicity, potential harm to human beings and the toxic emissions during production and use and after use. This environmental pressure has led to the development of new thermal processes for wood protection. Most heat treatment processes are carried out at temperatures ranging from 180 °C to 260 °C under low oxygen conditions (Podgorski et al. 2007). Heating vectors for wood thermal treatments include air, oil and liquid solutions (Rapp 2001). Table 1 presents the main commercial heat treatment processes for wood and their operating parameters.

In the last decade, there has been growing interest in oil-based processes for heat treating wood (Rapp and Sailer 2001, Treu *et al.* 2003). For example, the German company Menz Holz has developed an oil-based treatment performed in a closed process vessel in which hot oil circulates around the wood at a constant high temperature (Rapp 2001, Homan and Jorissen 2004). Another oil-based treatment called the “Royal Process,” was developed and patented by Häger for drying treated timber (Powell 2003). Other studies (e.g., Sailer *et al.* 2000) have reported that treating spruce and pine wood in a linseed oil bath at temperatures ranging from 180 °C to 220 °C improved resistance to *Coniophora puteana*.

The use of oil for heat treating wood has several advantages, including a relatively low treatment time, generally simple processes and the fact that the oil can be recycled. However, oils have a complex structure and variable chemical composition, which leads to high fluctuation in the treated products. The use of bioesters instead of oil as a vector for wood heat treatment can overcome these drawbacks and result in more efficient heat treatment of wood.

Bioesters are obtained from fatty acids contained in virgin and used vegetal oils and animal fats. Compared to vegetable oils (Table 2), they have low viscosity and high thermal stability and oxidation resistance, and they are more commercially available. Table 1 presents comparative data on the physical and thermal properties of vegetable oils and bioesters prepared from vegetable oils.

The general objective of this study was to develop a new process to thermally treat wood using bio-residues. More specifically, the aim was to use bioesters from used oils and animal fat to thermally treat wood and to study the effects of the treatment on the physical and mechanical properties and durability of wood.

Table 1. Heat treatment processes for wood and their operating parameters (Rapp 2001)

Process	Heating energy	Heat treatment	Thermal Vector	Pressure	Treatment Time
ThermoWood	Electricity / Thermal oil	230 °C	Air + Steam	No	≈ 33 days
Perdure	Gas	230 °C	Air	No	7–16 h
Retification	Electricity /Gas	245 °C	Air	No	8–10 h
Plato	-	180 °C	Air + Steam	Yes	16-21 h + drying time
OHT	Electricity / Thermal oil	220 °C	Oil	Yes	≈ 8 h
Thermoholz	Thermal oil	220 °C	Air	No	25–27 h
Intemporis	Gaz	200 °C	Air	Yes	20–25 h

Table 2. Physical and thermal properties of vegetable oils and bioesters prepared from vegetable oils (Srivastava and Prasad 2000; Agarwal, 2007)

Oil / Bioester	Viscosity cSt at 40 °C	Heating value (MJ/kg)	Flash point (ºC)	Density (g/cm^3)
	Vegetable oil			
Linseed	22.2	39.3	241	0.924
Peanut	39.6	49.8	271	0.903
Soyabean	32.6	39.6	254	0.914
Sunflower	33.9	39.6	274	0.916
	Bioesters derived from vegetable oil			
Linseed	3.6	35.3	176	0.874
Peanut	4.9	33.6	176	0.883
Soyabean	4.5	33.5	178	0.885
Sunflower	4.6	33.5	183	0.860

2. Methodology

The heat treatment consisted of immerging the wood in a bioester bath heated at temperatures ranging from 150 °C to 200 °C for two time periods of 20 and 30 minutes. Commercial bioesters, obtained by catalytic esterification of fatty acids contained in virgin or waste vegetal oils and animal fats, were used as a heat vector. Table 3 presents the properties of the bioesters used. Planks of balsam fir wood (*Abies balsamea*) of 2.5 cm thickness, 5 cm width and 50 cm length were treated. Planks of tamarack wood (*Larix laricina*) and hybrid poplar wood (*Populus x euramericana*) were also treated to compare mould resistance.

Table 3. Properties of bioesters

Property	Value	Property	Value
Density, kg/m^3	895	Boiling Point, °C	
Kinematic Viscosity @ 40 °C, cSt	5.5	IBP	297
Flash point, °C	170	T 50 %	357
Pour point, °C	1.3	T 97 %	451
Carbon Conrads on Residue, wt.%	0.08	Total glycerine content, wt.%	0.23
Sulphur content, ppm	9.1	Water and sediment, vol.%	0.4

The flexural modulus of elasticity (MOE) and the modulus of rupture (MOR) of treated and control balsam fir samples were tested according to ASTM D143. The water absorption and swelling of treated and control samples were measured according to ASTM-D1037 specifications.

The mould resistance of wood samples was evaluated according to ASTM D3273-00 standard method for assessing the resistance of surfaces of wood products to mould growth (anti-mould activity of formulations). A total of 27 treated and untreated wood samples of balsam fir, eastern larch and hybrid poplar were incubated in a mould-infected chamber at 25 °C and 100% relative humidity. Three fungi (described in ASTM D 3273), *Aureobasidium pullulans*, *Aspergillus niger* and *Penicillium citrinum*, were used as fungal infection sources in the mould growth chamber. The mould infection on each sample was inspected at 2-, 4-, 6- and 8-week incubation periods.

At each inspection, each sample was rated on a scale of 0 to 5 based on the surface coverage of mould growth on the 2 faces and 4 edges of the sample: 0 = no mould growth; 1 = mould growth on less than 5% of the sample surface area; 2 = mould growth on more than 5% but less than 25% of the sample surface area; 3 = mould growth on more than 25% but less than 50% of the sample surface area; 4 = mould growth on more than 50% but less than 75% of the sample surface area; and 5 = mould growth on more than 75% of the sample surface area. Average ratings for the 3 replicate samples of each treatment group were used to evaluate treatment effectiveness. The mould growth reduction on treated samples was calculated by comparing with mould growth on control samples.

The decay resistance of treated and control samples of balsam fir wood was tested according to AWPA E10-91 standard method for testing wood preservatives by laboratory soil-block cultures. The moisture content of each sample was determined by oven-drying at 103 $\pm$ 1 ºC. Samples for the decay test were dried at 50 ºC for 3 days to a constant weight and then weighed. One white-rot fungus, *Irpex lacteus*, and one brown-rot fungus, *Gloeophyllum trabeum*, was inoculated onto feeder strips placed in glass jars half-filled with soil prior to adding wood blocks. Treated and untreated wood samples were weighed and then exposed to decay fungi in glass jars, with 6 replicates per fungus, then incubated in an environmental chamber at 25 ºC and 75% relative humidity. After a 16-week incubation period, wood blocks were removed from the glass jars and the decayed fungal mycelia was cleaned from the samples. Samples were weighed to determine wood moisture content after decay. All samples were dried at 50 ºC for 3 days to a constant weight and then weighed to determine weight loss percentage. The decay resistance of heat-treated fir samples was determined by the average weight loss of treated samples exposed to each decay fungus and compared with untreated controls.

3. Results and Discussion

3.1 Dimensional stability

The beneficial effect of heat treatment on the dimensional stability of wood has been well documented (e.g., Esteves and Pereira 2009; Viitanen et al. 1994). The heat treatment of wood using bioesters also substantially improved the dimensional stability of the wood, as shown in Figure 1. The percentage of water absorption at different swelling times is shown for treated samples at 150 °C and 200 °C and for control samples (Figure 1A). It can be clearly seen that water absorption has been substantially reduced by the biothermal treatment, with a more substantial reduction at 200 °C than at 150 °C. Similarly, the biothermal treatment at both temperatures substantially decreased longitudinal (Figure 1B), radial (1C) and tangential (1D) swelling. Treatment at 200 °C also resulted in lower swelling values than that at 150 °C.

3.2 Flexural properties

It is well known that heat treatments have negative effects on wood strength (e.g., Esteves and Pereira 2009; Viitanen et al. 1994). The same trend was obtained in this study for MOE (Figure 2A) and MOR (Figure 2B) in bending. Both treatment temperatures decreased MOE and MOR. The higher the treatment temperature, the lower are the MOE and MOR. Similarly, increasing the treatment time lowered both properties.

3.3 Mould resistance

Test data for the evaluation of mould growth on each testing sample after 8-week testing are summarized in Figure 3. All treatments were effective to reduce mould growth on wood. Balsam fir showed better mould resistance than larch and hybrid poplar samples. For fir, the reduction in mould growth on treated samples was between 87% and 100%; for larch, between 75% and 100%; and for hybrid poplar, between 61% and 100%. In general, wood samples treated at 180

°C for 30 minutes were more resistant to mould infection than those treated at 200 °C for 30 minutes.

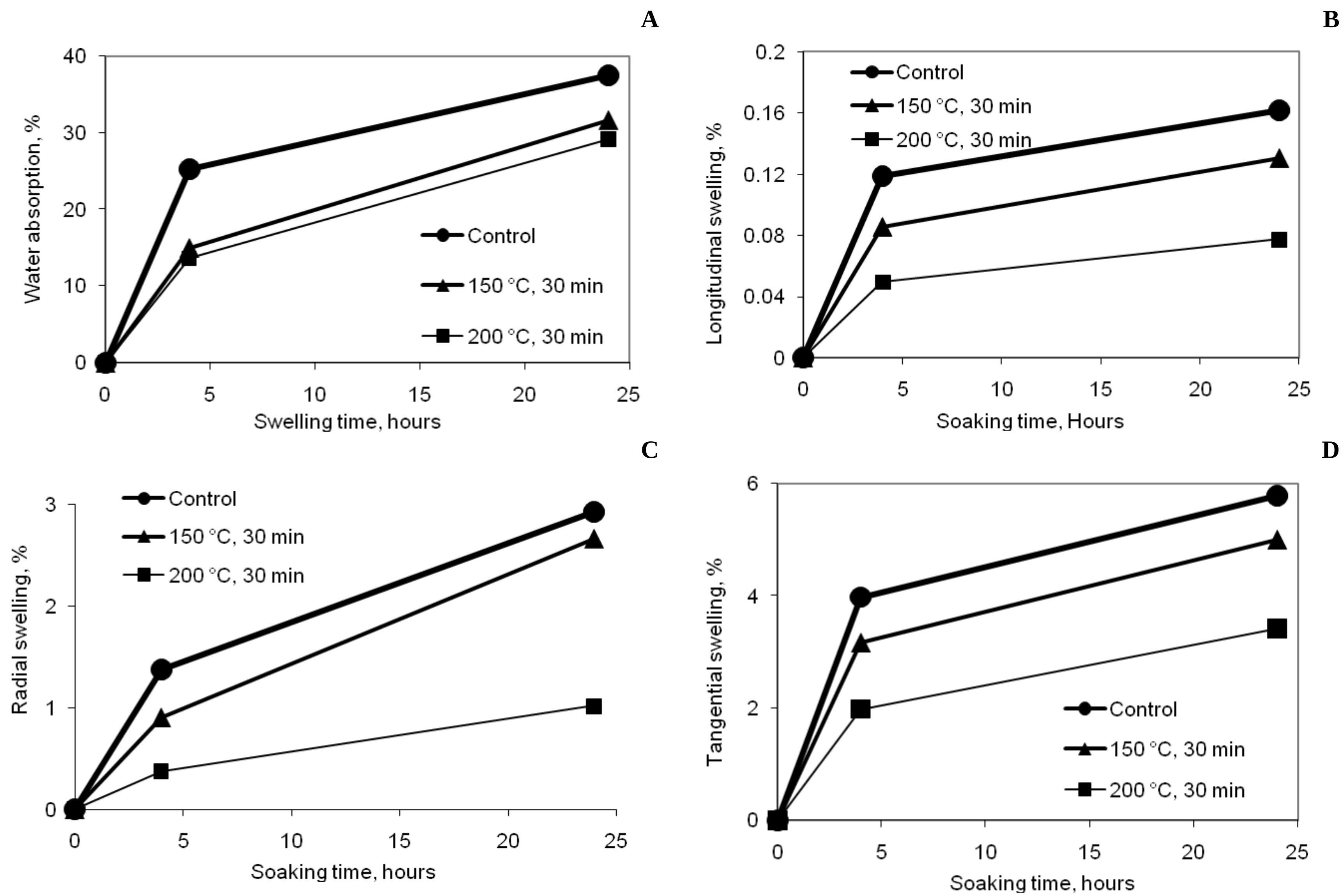
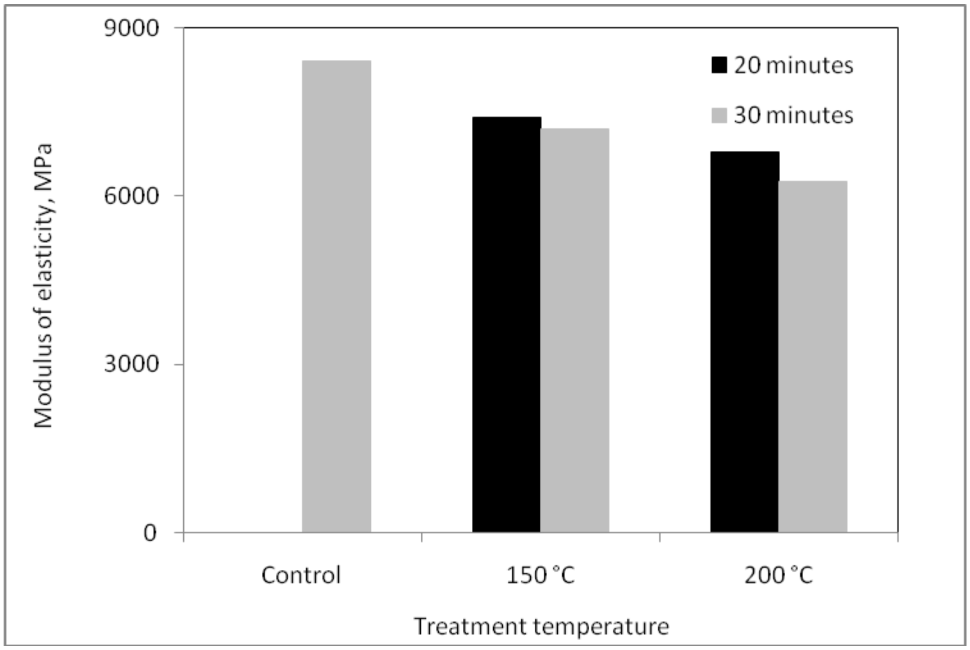


Figure 1. Impact of biothermal treatment on A. Water absorption; B. Longitudinal swelling; C. Radial swelling; and D. Tangential swelling for balsam fir (*Abies balsamea*)

A



B

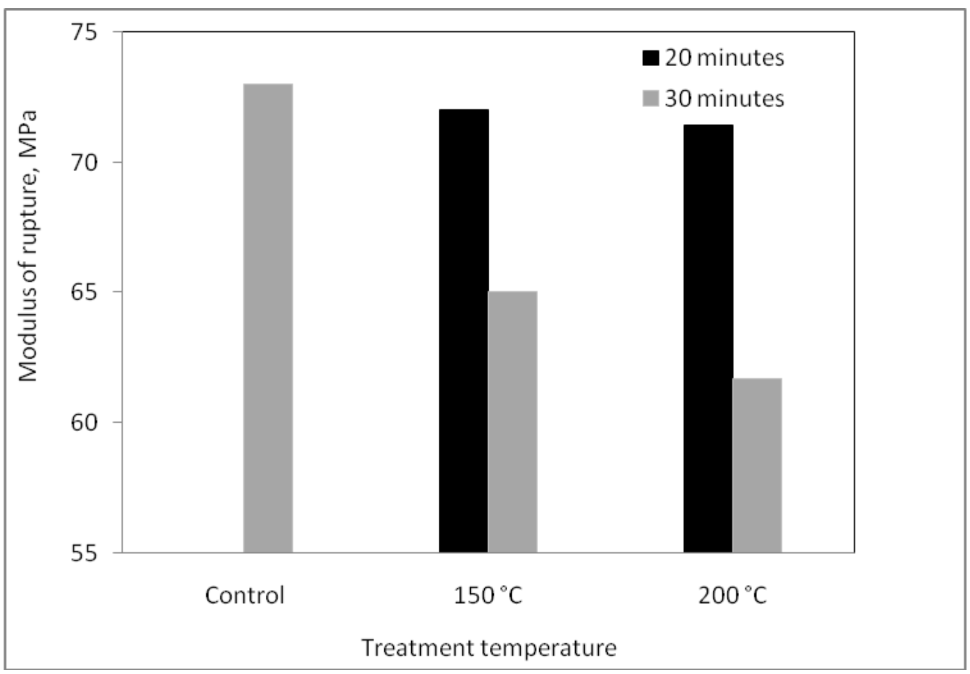


Figure 2. Impact of biothermal treatment on A. Flexural modulus of elasticity (MOE) and B. Flexural modulus of rupture (MOR) for balsam fir (*Abies balsamea*)

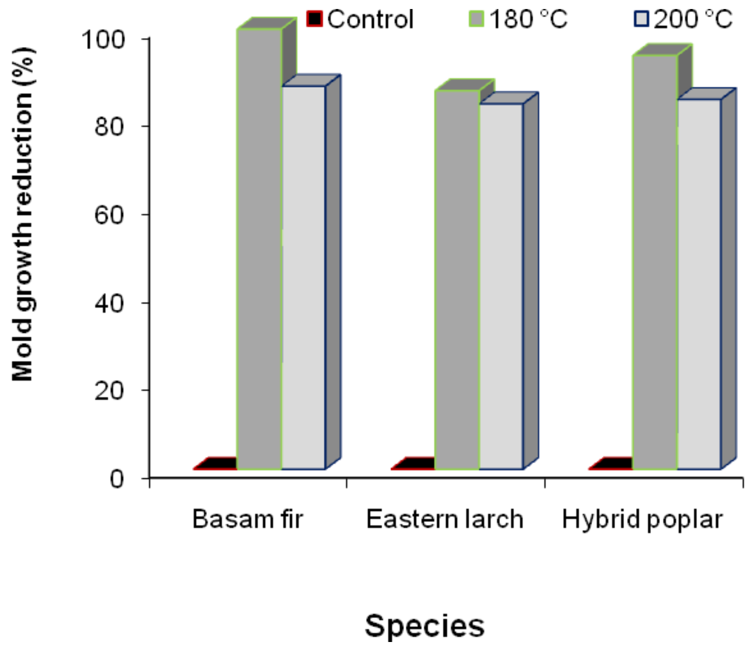


Figure 3. Effect of biothermal treatment on mould growth after 8 weeks of exposure on balsam fir, eastern larch and hybrid poplar

3.4 Decay resistance

The moisture contents (MC) of treated and untreated balsam fir samples before and after the decay test are presented in Figure 4. Samples treated at 180 ºC for 30 minutes had similar MC to untreated controls at around 9–10%, whereas samples treated at 200 ºC for 30 minutes had slightly lower MC. Untreated samples absorbed more MC from the environment when exposed to the brown-rot fungus *G. trabeum* than when exposed to the white-rot fungus *T. versicolor* (131% vs. 105% respectively). Compared with untreated control samples, heat-treated fir samples absorbed more water when exposed to brown-rot fungus and less when exposed to white-rot fungus.

Untreated control samples were seriously decayed after exposure to decay fungi for 16 weeks. The average weight loss for samples exposed to white-rot fungus was 31% and for those exposed to brown-rot fungus it was 57% (Figure 5). Heat-treated fir samples showed less weight loss than untreated controls, at 27% (for both treatments) when exposed to white-rot fungus and 40–46% (200 ºC vs. 180 ºC) when exposed to brown-rot fungus. These weight loss differences between treated and untreated wood do not support the effectiveness of the treatment against wood decay for soil contact use. In a similar lab test, weight loss of wood samples treated with the currently used wood preservative ACQ and exposed to white-rot and brown-rot fungi was less than 2.5%.

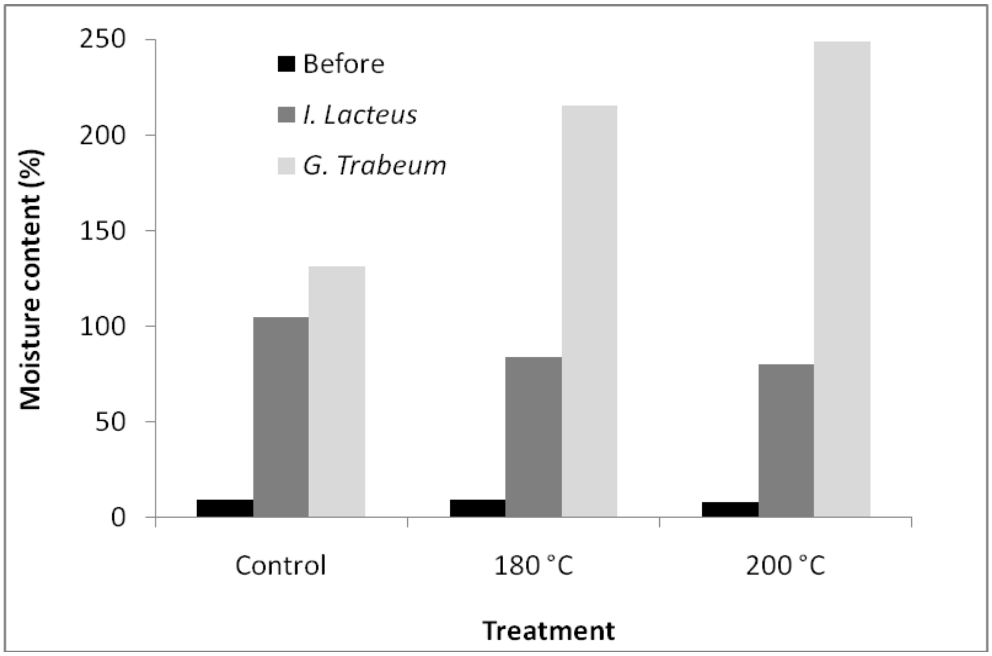


Figure 4. Moisture content of treated and control samples before and after decay with exposure to white-rot fungus *Irpex lacteus* and brown-rot fungus *Gloeophyllum trabeum*

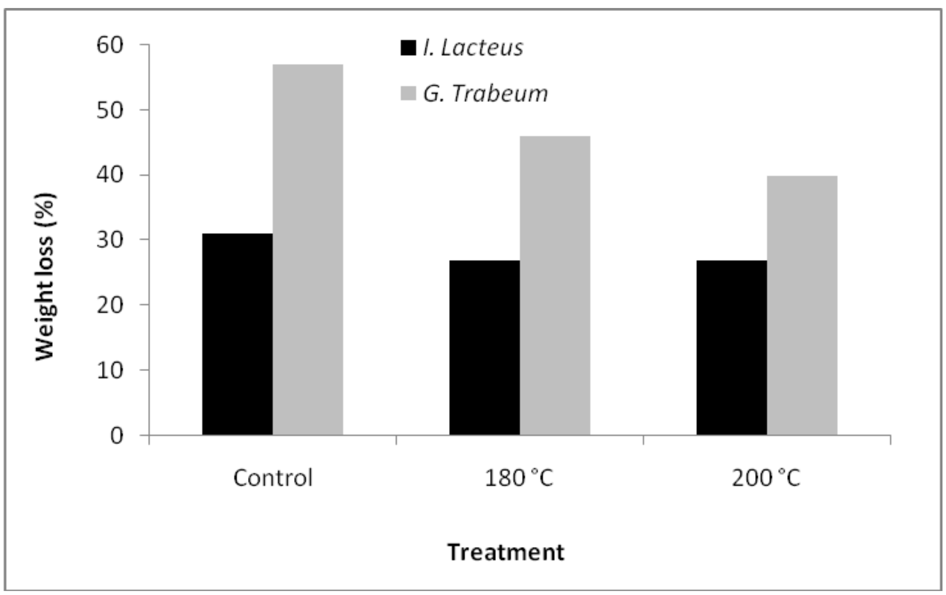


Figure 5. Weight loss for treated and control balsam fir wood samples after decay with exposure to white-rot fungus *Irpex lacteus* and brown-rot fungus *Gloeophyllum trabeum*

4. Conclusions

The use of bioesters for thermal treatment of balsam fir wood resulted in a substantial improvement in dimensional stability. However, it decreased the bending properties.
The treatment also resulted in a substantial improvement in mould resistance, but had no impact on decay resistance.

5. Literature

American Society of Testing and Materials (ASTM) Standard D3273-00. 2000. Standard test method for resistance to growth of mold on the surface of interior coatings in an environmental chamber. Annual Book of ASTM Standards. ASTM, West Conshohocken, PA, USA. pp. 358-361.

American Wood-Preservers' Association, Standard E10-91:1-11. 1991. Standard Method of Testing Wood Preservatives by Laboratory Soil-Block Cultures. American Wood Preservers' Association. Stevensville, Maryland, USA.

Avinash K. A. 2007. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. Progress in Energy and Combustion Science33: 233-271.

Esteves B. and H. Pereira. 2009. Wood modification by heat treatment: A review. BioResources. Vol 4 (1): 370-404.

Hakkou M., M. Pétrissans, P. Gerardin and A. Zoulalian. 2006. Investigation of the reasons for fungal durability of heat treated beech wood. Polym. Degrad. Stab. 9 (2) : 393–399.

Homan W.J., A.J.M. Jorissen. 2004. Wood modification developments. HERON. 49(4): 361-386.

Kamdem D.P., A. Pizzi and A. Jermannaud. 2002. Durability of heat-treated wood. Holz als Roh- und Werkstoff; 60: 1-6.

Podgorski L., I. Le Bayon, I. Paulmier, J.D. Lanvin, D. Grenier, H. Baillères, J.-M. Méot. 2007. Bi-oleothermal Treatment of Wood at Atmospheric Pressure: Biological Properties, Weatherability and Coatability. Pages 87-97 Hill et al. Eds. Proc. The Third European Conference on Wood Modification. Cardiff, UK. 15-16th October 2007.

Powell M.R. 2003. Treatment of wood with royale stabilising oil. In: Proceedings of the First European Conference on Wood Modification. Ghent, Belgium, pp 15-22.

Rapp A.O. 2001. Review on heat treatments of wood. Proc of the special seminar held in Antibes, France, on 9 February 2001, Forestry and forestry products, France. COST Action E22.

Rapp A.O. and M. Sailer. 2001. Oil heat treatment of wood in Germany-State of the art. Review on heat treatments of wood. In : Rapp AO (ed) proc of the special seminar held in Antibes, France, on 9 February 2001, Forestry and forestry products, France. COST Action E22, EUR 1985, pp 43-60, (2001).

Sailer M., O.A. Rapp, and H. Leithoff. 2000. Improved resistance of Scots pine and spruce by application of an oil-heat treatment. The International Research Group on Wood Preservation. Document No.IRG/WP 00-40162, 16p.

Srivastava A., R. Prasad. 2000. Triglycerides-based diesel fuels. Renew Sustain Energy Review 4:111-33.

Treu, A., J. Habicht, R. Klaucke, H. Militz. 2003. Improvement of wood properties by a combined impregnation process-the royal process. In: Proceedings of the First European Conference on Wood Modification. Ghent, Belgium, pp 3-13.

Viitanen, H.A. S. Jämsä, L.M. Paajanen, A.J. Nurmi, and P. Viitaniemi. 1994. The effect of heat treatment on the properties of spruce. Intern. Res. Group on Wood Preservation, Doc. No. IRG/WP 94-40032.