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Assessment of Heat-Treated Jack Pine and Balsam Fir

By

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Summary

Industrial heat treatment technology for wood has been under development since the 1970s. The technology consists in heating wood to temperatures of from 150°C to 240°C while preventing it from burning. This is achieved by heating the wood in either an inert atmosphere or saturated vapour environment. Heating the wood over 200°C changes the chemical structure of the wood and results in a reduction in its hydrophilic behaviour. After heat treatment when wood colour has changed to brown, an improvement in dimensional stability and biological durability should be observed. However, some mechanical properties of the wood may have decreased. This enhanced dimensional stability and biological durability make heat treatment an interesting option for the protection of wood used in exterior applications. The objectives of this study are to assess the performance of heat treatment technologies and to determine the properties of jack pine and balsam fir after heat treatment, as regards to exterior applications. Owing to difficulties in the start-up period that significantly delayed the project, no experimental work had been conducted by the end of March 2003. The lumber has however been sent to two companies for treatment and the physical and mechanical tests will be conducted under a new project entitled "Quality Control and Certification of Thermally Modified Wood." A final report will be issued at the end of March 2004.

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1 Objectives

- Assess performance of heat treatment technologies;
- Determine wood properties after heat treatment as regards exterior applications.

2 Introduction

Industrial heat treatment technology for wood has been under development since the 1970s. The technology consists in heating wood to temperatures of from 150°C to 240°C while preventing it from burning. This is achieved by heating the wood in either an inert atmosphere or saturated vapour environment. Heating the wood over 200°C changes its chemical structure and results in a reduction in its hydrophilic behaviour (Rapp, 2002). After the heat treatment when wood colour has changed to brown, an improvement in dimensional stability and biological durability should be observed. However, some mechanical properties of the wood may have decreased. This enhanced dimensional stability and biological durability make heat treatment an interesting option for the protection of wood in exterior applications. Owing to ever-increasing environmental pressure on the use of CCA treatment, one can expect restrictions on such treatments in the near future. Decking, fencing and playground products will especially be affected by CCA restrictions. Heat treatment costs vary from an estimated $100 to $130/1000 bf, compared with about $100/1000 bf for CCA treatment. Western Red Cedar decking and fencing grades sell for about $800/1000 bf. Heat treatment has the potential to improve some wood properties, but its impact depends on the wood species used. Balsam fir and jack pine are two under-utilized species in Eastern Canada and heat treatment may well be an opportunity to add value to that resource.

The initial target of the present study was to assess three heat treatment technologies that seemed to be in industrial use: Thermowood (T^{o}W) developed by the Technical Research Center of Finland (VTT); New Option Wood (NOW), also known as Retitech, developed by Ecole des Mines de St-Étienne in France; and Le Bois Perdure, developed by BCI-MBS in France. The patents of the latter are now owned by Quebec-based Pluri capital inc. Project start-up was delayed to July 2002, owing to the delay in receiving approval under the Value to Wood Program. During that period, interest in heat treatment increased and three additional firms promoting heat treatment technologies expressed interest in participating in the study. They were In Wood International of Switzerland (IWI, Intemporis); Plato Wood from the Netherlands, which went bankrupt in 2001 but resumed operations in 2002; and the Canadian firm ThermoBois inc., which planned to start-up operations by fall 2002. A decision was therefore made to include these technologies in the study and expand the project into the year 2003. Mechanical testing was scheduled to be performed in 2002 and the longer decay resistance and ageing tests were scheduled for the end of 2003. To cover the costs of the work to be performed in fiscal 2003/2004, the decay and ageing tests were integrated into a new project entitled “Quality Control and Certification of Thermally Modified Wood” scheduled to start in April 2003.

Material supply problems for 2 in x 6 in jack pine boards further delayed the research work. In the meantime, the IWI facility in Switzerland was destroyed by fire and ThermoBois delayed the opening of their plant. The NOW treatment was supposed to be carried out in a Québec-based facility but the facility never started operations. The cost to have the treatment performed by VTT in Finland was substantial, and negotiations are continuing to reduce these costs to an acceptable level. The lumber was finally sent to PCI Bois Perdure in Quebec, and Plato Wood in the Netherlands in February 2003. IWI is willing to treat the lumber in the spring 2003 when the facility resumes operations. Since no results for the present study were available by the end of March 2003, it was proposed to perform testing on a smaller scale under the new project starting in April 2003.

3 Background

Scientific research on thermal modification began in the late 1930s in the USA and Germany. Different heat treatment methods have since been developed and the main technologies are presented in the following chapters. Note that the German Menz Holz technology was not included in the present study because this process uses linseed oil as a heating vector, which results in a thermally modified and oil-impregnated product.

3.1 PCI Bois Perdure Process

PCI inc. of Jonquière, Quebec, acquired rights in 2001 to use a technology developed by BCI of France and trade marked Bois Perdure. In 1996, the first industrial-scale treatment facility was set up in France. There are currently five production sites in operation in Canada, France, and Denmark. Typical kiln dimensions are shown in Table 1.

Table 1: Typical Kiln Dimensions for the Bois Perdure Technology

	Length (m)	Width (m)	Height (m)
Total dimensions	11	3	4.5
Utility dimensions	4.5	1.45	2.15

The kiln is heated using propane gas. Gas emissions from the wood are directed to the combustion chamber and used to heat the kiln. If the out-gassing of the wood is insufficient to increase or maintain the kiln temperature, additional propane gas is injected. Green lumber may be used, but pre-drying to about 10% moisture content (MC) is suggested to limit lumber degrade after treatment. Using pre-dried lumber also reduces the kiln treatment cycle, and hence increases treatment capacity. Treatment is performed in a saturated water vapour environment. Cycle time may vary between 12 and 24 hours. Parameters affecting treatment results are wood species, lumber dimensions, initial moisture content and treatment process control.

The Bois Perdure technology is protected by patent No. FR – 97/01993 in Canada, Europe, USA, and Brazil.

3.2 New Option Wood (NOW) Process

The origins of the NOW technology date back to the 1970s when the École des Mines in St-Étienne, France, started developing the process. Three patents, FR 26 04942, Fr 27 51579, and FR 27 51580, have been acquired. The technology is called retification (retified wood). Typical kiln sizes are indicated in Table 2.

Table 2: Typical Kiln Dimensions for the NOW Technology

TYPE	Power (kW)	Utility dimensions (m)			Capacity (m3)	Yearly capacity* (m3)
		W	L	H		
R3	230	1.20	3	2.20	4	1,760
R4,5	330	1.20	4.5	2.20	6	2,640
R6	430	1.20	6	2.20	8	3,520

*Yearly capacity is based on an average of two loads/day and 220 days/year

Lumber should be dried to about 15% MC prior to treatment, which is carried out in a nitrogen environment. Cycle time amounts to about eight hours for 4/4 inch thick lumber.

The first facility started operations in France in 1997. Today, there are at least four sites in operation. Figure 1 shows an R3 type kiln in France.

Figure 1: NOW Treatment Facility in France

3.3 Plato Wood Process

The *Plato Wood* process was initially developed by SHELL laboratories to improve the energy efficiency of wood combustibles. Three patents, No. 95-US-545 1361, No 96-US-555 5642, and No 97-US-563 3299, have been acquired for the technology. Lumber should be dried to about 18% MC prior to treatment, which is divided into three distinct phases: hydrothermolysis, drying, and hardening.

Hydrothermolysis is performed at 150°C to 200°C under super atmospheric pressure in a water vapour environment. Lumber is not dried during this first 30-minute phase, but some changes in wood structure occur. The wood is conventionally dried to about 10% MC in the second phase of the treatment. The third phase entails heat treatment in a water vapour environment at 170°C to 190°C for 15 to 18 hours. Hardening of the wood as well as some other changes in the chemical structure of the wood occur during this phase. The last step involves a conditioning period of two to 15 days.

One facility is in operation in the Netherlands. The plant consists of two 20-m^3 kilns for the first phase of the treatment, eight 160-m^3 conventional kilns and one 80-m^3 kiln for the last phase of the process. Based on 300 days of operations per year, the annual capacity of this plant would be 25,000 $m^{3.}$

3.4 ThermoWood Process

In 2002, Finland was the number one producer of heat-treated wood. The 13 Finnish companies using the *ThermoWood* technology under license have yearly treatment capacity of some 100,000 m^3 . The technology was developed by the Technical Research Center of Finland (VTT) and is based on three patents: No. 94 FI 945 338, No. 94 FI 002 210, and No. 94 FI 002 209. The treatment kiln, which has a typical capacity of about 100 m^3, may also be used as conventional kiln. The process involves a phase where the wood temperature is raised rapidly to 100°C using heat and steam. Thereafter the temperature is increased steadily to 130°C. Green or dried wood may be used as raw material . The actual heat treatment may be performed at different temperatures varying from 185°C to 215°C. The treatment cycle time amounts to three hours in a steam atmosphere. The last step involves a conditioning and stabilization period. Total treatment cycle time runs about 36 hours. The VTT classifies the treated wood into three categories:

Heat treatment class 1:

Treatment temperature: over 180°C

- for above-ground applications
- for permanently dry conditions
- equilibrium MC of untreated wood to remain permanently under 18%
- for products such as furniture, flooring, and interior siding.

Heat treatment class 2:

Treatment temperature: over 210°C

- for above-ground applications
- exposed to occasional wetting
- equilibrium MC of untreated wood to remain permanently under 20%
- for products such as windows, exterior siding, and garden furniture.

Heat treatment class 3:

Treatment temperature: over 230°C

- for above ground applications
- exposed to frequent wetting
- equilibrium MC of untreated wood may exceed 20%
- for products such as fences or decking

More than ten companies performing heat treatment in Finland are members of the Finnish Thermowood Association founded in 2001. Four manufacturers produce *ThermoWood* heat treatment equipment. A picture of a *ThermoWood* facility is shown in figures 2 and 3. The tunnel-type kiln shown in Figure 3 aligns the different treatment phases into one kiln. Lumber moves from one treatment step to the next in a continuous flow through different sections of the tunnel.

Figure 2: Thermo Wood Facility in Finland

Figure 3: Thermo Wood Continuous Through Feed Treatment Facility

3.5 In Wood International Process

In Wood International of Switzerland is the owner of the *Intemporis* trademark. No technical information was available regarding their process. Their production covers flooring, siding, posts & beams and rough lumber.

3.6 Properties of Thermally Modified Wood

This chapter provides an overview of the impact of thermal modification on wood properties and summarizes some of the main issues regarding thermally modified wood. A technical overview of this subject will be published under the *Value to Wood* program.

Thermally Modified Wood

When wood is exposed to high temperature, its chemical structure is modified. For a number of years, research has been conducted on the effects of such modifications on the physical and mechanical properties of wood products. Several thermal modification techniques have been developed, and a number of related patents issued.

What is the difference between thermally modified wood and heat-treated wood?

"Heat treatment" has been used to describe the wood pasteurization process, particularly in the context of pallet manufacturing. To avoid confusion, the expression "thermal modification" is meant to describe the use of heat to modify the chemical structure as well as other properties of wood. In this report, however, “heat treatment” and “thermal modification” are used synonymously.

What is the temperature used to thermally modify wood?

The processing temperature is between 180°C and 280°C, i.e. somewhere between high-temperature drying and torrefaction levels (Chanrion and Schreiber, 2002). To prevent wood combustion, the process takes place in the absence of oxygen.

How does thermal treatment affect the wood structure?

The thermal process modifies the three major constituents of wood: cellulose, lignin, and hemicelluloses. Modification of cellulose and lignin causes changes to the mechanical properties of wood. Degradation of hemicelluloses causes changes to the physical properties (hygroscopic behaviour).

How does thermal modification affect wood properties?

Thermal modification affects most of the physical and mechanical properties of wood. The properties that are the most significantly modified are as follows:

Colour

The process modifies the natural colour of the wood, typically turning it to tobacco brown, although this will vary with processing temperatures. The new colour is uniform throughout the thickness. Thus, thermal modification can be used to impart the appearance of a high-value wood species (e.g., cherry, teak, walnut) to a low-value species. The treatment can also mask blue stain defects.

Dimensional stability

Hemicellulose degradation changes the hygroscopic behaviour of wood. Moisture absorption is reduced, and any water penetrating into the wood evaporates quickly, as it does not become adsorbed; this contributes to enhancing dimensional stability as well as fungal resistance (Militz, 2002).

Fungal resistance

Wood degrading fungi require very specific conditions; the material's moisture content must be around 20%. If the wood is too dry or too wet, white rot and brown rot fungi cannot grow. As a result of heat-induced changes to hygroscopic properties, conditions favourable to fungal growth rarely occur, so that wood resistance to fungal attack is enhanced. It is worth noting, however, that ground contact will create conditions favourable to fungal development, even in thermally modified wood. Thermally treated wood exposed to ground contact will in fact deteriorate just as rapidly as untreated wood.

Mechanical properties

Thermal modification affects the crystalline structure of cellulose, with resulting changes to mechanical properties. Although treated wood tends to be more brittle, this need not interfere with most appearance applications such as wall siding, patio or garden furniture. Based on current knowledge, the use of thermally modified wood in structural applications is inadvisable.

It should be kept in mind that thermally modified wood is a new material. It needs to be applied accordingly, which involves adjustments to working methods. For example, thermally modified wood is easy to machine, but the processing residue is a fine dust; friction of such dust in conventional collection systems may cause a fire unless dust-collection conduits are grounded. Strength reductions must be taken into account in the design of furniture. Thermally treated wood is also more acidic, and metal fasteners used in assemblies should be made of galvanized or stainless steel.

What factors, other than process parameters, affect treatment results?

Thermal treatment results are affected by the following three factors:

Species

Heat-induced modifications to physical and mechanical properties vary from one species to another.

Initial wood moisture content

High initial moisture content tends to delay the effects of thermal treatment on wood properties.

Lumber thickness

Wood product thickness affects the time required to achieve the desired modifications.

Can thermal treatment replace chromated-copper arsenate (CCA) treatment?

Thermally treated wood can be used as a substitute for CCA-treated wood in some applications, provided they are non-structural and not in contact with the ground.

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5 Materials and Methods

5.1 Materials

Selected species for the present study are jack pine and balsam fir. One cubic meter of 2 in. x 6 in. boards of each species was shipped for treatment to selected companies. Another cubic meter of each species was kept in the laboratory as control samples# The lumber was of the select or better grade, dried to a MC of 10%, and cut to four-foot lengths prior to shipment. All boards were identified by wood chisel marks at one end.

5.2 Methodology

The heat treatment is expected to be performed by four different companies: *Bois Perdure, NOW, ThermoWood* and *IWI.* Temperature for the treatment will be around 220°C depending on the companies' capability. Cycle time and temperature along with basic information on each heat treatment process will be documented. A series of standard tests will be performed to determine the mechanical and physical properties of the wood. Treated as well as untreated lumber will be assessed and results compared.

5.2.1 Visual Inspection of Wood Colour

Upon receipt of the heat-treated wood, the lumber will be planed as part of sample preparation for the following tests. Colour uniformity, bend, warp and twist in addition to surface checks and cell collapse will be evaluated. Pictures of lumber sections and surfaces will be taken to document the visual results of the treatment.

5.2.2 Dimensional Stability

Six boards x 2 species x 5groups (each of the treatment technology + the untreated lumber) = 60 2 x 6 x 30 in. boards will be dipped in water at 20°C for 24 hours. The lumber will than be dried in a conditioning chamber at 20°C and 20% RH for seven days. This cycle will be repeated four times. Width, thickness, length and deformation (bend, warp, twist) will be measured at the end of each cycle.

5.2.3 Fungal Decay Resistance

The fungal decay resistance test will be performed using American Wood Preservers Association (AWPA) E-10-91 “Standard method of testing wood preservatives by laboratory soil block cultures”. Ten samples x 4 fungus x 2 species x 6 groups = 480 ¾ x ¾ x ¾ in. samples will be exposed to brown rot fungus (Gloephyllum trabeum and Posita placenta) and white rot fungus (Trametes versicolor and Irpex lacteus). Decay will be evaluated as a function of the loss of wood mass. CCA-treated jack pine will be included in this test.

5.2.4 Hardness

Wood hardness will be measured using the *American Society for Testing and Materials (ASTM) D 143 “Standard methods for testing small clear specimens of timber”*. Twenty samples x 2 species x 5 groups = 200 ¾ x 2 x 6 in. samples will be tested. The test, also called the “Janka hardness test”, consists in measuring the pressure required to embed a sphere with a diameter of 11.3 mm into the wood to a depth of half the sphere's diameter.

5.2.5 Impact Resistance

Impact resistance will be measured using *American Society for Testing and Materials (ASTM) D 143 “Standard methods for testing small clear specimens of timber”*. Twenty samples x 2 species x 5 groups = 200 ¾ x 2 x 30 in. samples will be tested. A 50-lb. weight will be dropped from different heights onto the sample. The maximum height measured before sample fracture serves as an indicator of impact resistance.

5.2.6 MOE and MOR

The modulus of elasticity (MOE) and the modulus of rupture (MOR) will be determined using *American Society for Testing and Materials (ASTM) D 143 "Standard methods for testing small clear specimens of timber"*. 40 samples x 2 species x 5 groups = 400 ¾ x ¾ x 12.5 in. samples will be tested.

5.2.7 Abrasion

An abrasion resistance test will be performed using the *Taber Abraser* equipped with a H22 (very coarse) abrasive role and a 1-kg load. Abrasion resistance will be measured as sample weight loss per 100 revolutions of the disc. Ten samples x 2 species x 5 groups = 100 4 x 4 in. samples will be tested.

The abrasion resistance test will be performed instead of the screw and nail withdrawal tests initially planned. The accelerated ageing test will not be conducted.

6 Results and Discussion

Since no results were available at the end March 2003, the tests will be conducted under a new project entitled "Quality control and certification of thermally modified wood".

7 Conclusions

Numerous difficulties during the start-up phase of the present project delayed the experimental work. Although no results were available at the end of March 2003, some material has been sent for heat treatment to companies in the Netherlands and Canada. Work will be completed by the end of March 2004.

Thermal modification of wood has potential for particular applications, as shown in the examples in figures 4 to 6. Since heat treatment changes the structure of the wood, thermally modified wood has to be considered as a new material. This should be taken into account in processing. For example, since machining generates very fine (dust-like), dry residues, dust aspiration systems have to be grounded to prevent explosions. Also, since the pH of the wood changes and becomes more acid, in exterior applications, all fasteners should be either stainless steel or galvanized. The structural weakness of thermally modified wood must be considered in product design. Assembled systems should be developed as a function of material properties, as demonstrated by the garden furniture shown in Figure 4. The components of the chairs requiring more structural strength (legs) are made out of aluminium, whereas those components requiring less strength are made out of thermally modified wood.

Some companies are currently in the process of setting up heat treatment facilities. Research and development is needed to overcome problems related to the heat treatment process and such issues as quality control and product certification. The years ahead will show whether there is a market for thermally modified wood.

Figure 4: Garden Furniture

Figure 5: Exterior Siding on a Building in Norway

Figure 6: Thermally Modified Wood Used for Log Home Construction

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