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THERMOWOOD: BENEFITS OF HIGH TEMPERATURE KILNS

Mathew Leitch
Lakehead University, 955 Oliver Road, Thunder Bay, ON, P7B 5E1

Summary

The Thermowood process is essentially a high temperature kiln that operates between 180°C & 230°C wood temperature. The process requires around 36 hours for a complete run from green to 5-8% MC and requires no chemical inputs. Many properties are modified during the process making the final product very unique. Lakehead University Wood Science and Testing Facility (LUWSTF) has conducted tests on the Thermowood products produced at Superior Thermowood® based just outside Thunder Bay, Ontario. To date LUWSTF has tested Black Ash, Jack Pine, Balsam Fir, Poplar, White Spruce, White Pine, Tamarack and White Birch Thermowood products. Mechanical tests include hardness, MOE, MOR, and nail & screw withdrawal. In general, properties varied depending on the temperature of the run with the 200°C cook producing the best overall results. The 230°C cook produced the greatest aesthetic color enhancement, while the 180°C cook produced wood with little aesthetic enhancement and mechanical properties very similar to controls. Depending on the cook temperature the resulting mechanical properties varied within a species and between species.

1. Introduction

Wood quality is generally characterized based on certain properties of a wood, and in particular those properties that enable a wood to be utilized for specific end products. The strength of wood differs within and between species (Wakefield, 1957). Some species are light, easy to work and strong for their weight; however, are not strong enough for many end products. Other species are heavy, more difficult to work and very strong for certain end product applications. The amount of cell wall material generally indicates the density of a wood and to a certain degree also indicates the quality of the wood (Panshin and DeZeeuw, 1980; Zobel and Talbert, 1984). It is this variety found in wood that allows us to utilize different species for different products based on the inherent properties of a given species (Wakefield, 1957). Density also regulates in many respects the mechanical properties of wood (Desch and Dinwoodie, 1981; Garratt, 1931; Porter, 1981) where higher density woods display higher mechanical properties (Herajarvi, 2004). With this in mind we can see why some wood properties such as flexure are better suited to the softwoods and their long slender tracheids while a property such as hardness is better suited to the short and very dense fibers of hardwoods. For example, hardwood flooring utilizes species such as sugar maple where the wood density is around 700 kg/m3 (Panshin and DeZeeuw, 1980) and displays extremely high strength properties (Burrows, 2000). At the lower end of the density scale toy model planes are made of the lightweight hardwood Balsa where the density is around 160 kg/m3 ((Desch and Dinwoodie, 1981). Softwoods are utilized more for structural lumber due to the inherent ability to flex and recover and so make up a large percentage of wood used in these applications. Within the industry there are several tests performed to determine the mechanical properties of a species, with the moisture content being at green and at 12%. For example a standard test for hardwoods to be used in flooring is the Janka Ball Hardness test which determines a woods ability to resist an intrusion by an object external to the material (Herajarvi, 2006; Garratt, 1931). A standard test for softwoods to calculate their strength is the Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) tests that determine the ability of a wood to absorb shock and maximum carrying capacity; respectively (Green et al., 2002). Many other mechanical tests exist that look at strength of wood in different ways for different end uses, for example, tension and compression perpendicular and parallel to the grain, cleavage, impact strength, adhesive strength and nail and screw holding ability. All tests serve a purpose in determining a woods ability to be utilized for specific products, particularly when strength is required in that product.

We have been testing and reporting commercial species properties for several years now (see Green et al., 2002) and have older literature on many of the species that grow in Canada and are not commercial (see Wakefield, 1957; Kennedy, 1965; Jessome, 1986). More recently we have seen the introduction of new technologies in the drying of wood, which has created wood species displaying properties much different than is reported in the literature for the particular species. One such technology is Thermowood, which is a process that originated in the early 1990's in Finland where commercial operations exist today (Finnish Thermowood Association (FTA), 2003). The process is essentially a high temperature kiln that operates between 180°C & 230°C. The degree of heat and time at that heat level depends on what species is being cooked and what end product is to be produced. The process requires around 36 hours for a complete run from green to 5-8% MC and requires no chemical inputs (FTA, 2003). The product displays increased R-values, thermal values, hardness and durability, aesthetic attractiveness and resistance to moisture and fungal attack (FTA, 2003).

A key opportunity in the forest industry with this process is the ability to utilize under-utilized species for use in value-added products. This paper presents some results for tests conducted on Thermowood products produced by Superior Thermowood®, located just outside of Thunder Bay, ON, Canada.

2. Methodology

Sample material

All sample material was provided by Superior Thermowood® (Kakabeka Falls, Ontario, Canada) following treatment (180°C, 200°C or 230°C wood temperature) in their kiln. Samples arrived as 2.5cm-3cm thick x 15cm wide x 240cm long rough sawn boards at a moisture content (MC) of between 5 and 8% MC. All boards were selected from the kiln stack in a pattern that ensured samples were removed from the top, middle and bottom of the stacks as well as from the right, center, left, front and back of the stacks. Within the sample boards an equal amount of boards displaying tangential as well as radial plane characteristics were selected so the average results represented both planes. All sample pieces were defect-free with as straight a grain as possible.

Sample preparation

All samples were prepared/processed in the LUWSTF. Initially the boards were tested for moisture content to ensure all were at the 5-8% level using an electronic moisture meter (Protimeter – *Surveymaster*). Following this all boards were put through a planer to clean both the top and bottom surface.

Hardness: four samples were collected at each end and four in the middle such that samples 1 and 2 were at the end of the board and samples 3 and 4 were immediately in from these. Middle of the board samples, were collected by removing two samples from each side of the exact middle of the board (samples 5 and 6 and, 7 and 8). Similar samples were collected from control boards that were removed from the stack prior to processing. All tests samples had a final dimension of 2.5cm x 7.5cm x 10cm (maximum thickness attainable due to sample boards arriving as raw flooring).

MOE: for modulus samples the boards were sawn into 20mm x 20mm x 300mm (H x W x L) dimensions. All samples were free of defects and while testing it was ensured that the rings were always facing down and ideally the rings were as close as possible to being parallel to the upper and lower surfaces of the sample with the rings arcing towards the bottom of the sample.

Nail and Screw Withdrawal: samples for this test were roughly 50mm x 75mm x 75mm (H x W x L). All samples were defect free and all nails/screws were inserted to the same depth by initially measuring and marking the nails/screws. Nails/screws were inserted in the middle of the sample surface to avoid splitting.

Microscopy: microscopy samples were prepared using a sliding microtome. All samples cut into 1 x 1 x 2cm blocks, placed in beakers of water and then placed under a vacuum until the air was removed from the samples. Once the air was removed the samples were mounted onto the microtome and sections roughly 5 - 10μm in thickness were cut. Sections were dehydrated and then re-hydrated with Toluene in order to allow mounting with Cover Bond Mounting Media (American Scientific Products). Sections were then viewed under a Zeiss Photomicroscope and micrographs were taken.

Thermal Characterization: For this study a small amount of each material to be tested was required. Wood was planed to acquire shavings, which were then ground using a Wiley Mill prior to testing in a Bomb Calorimeter (Parr Instrument 1241 Adiabatic Calorimeter). Samples for this unit required 0.5 grams of finely ground wood material.

Testing conditions

All tests were performed on a Tinius Olsen H10KT Universal Wood Testing Machine equipped with a Janka Ball Hardness Testing Tool (11.3 mm diameter ball), a 3-ptn flexure tool and a nail and screw withdrawal tool, all operated through a computer running Test Navigator Software designed by Tinius Olsen. The load was applied at a rate of 8mm/minute and results were recorded in Newton's (N) for hardness, MPa for MOE and kg for the nail/screw withdrawal tests. For hardness tests the run was halted manually when the collar around the ball tightened against the wood sample, for MOE it is when the sample failed (software ends test) and for nail/screw withdrawal it is when the nail/screw is released from the sample (software ends test).

Assessment

All results produced through the Test Navigator Software included, averages, COV, deviation as well as limits. Comparisons were made between controls, published values and the results presented here. Thermal values were tested using a sample t-test comparison between different species.

3. Results and Discussion

Mechanical Properties

Low temperature cook (180°C) equal to or slightly higher mechanical values than controls; Medium temperature cook (200°C) highest mechanical values over controls; and High temperature cook (230°C) lowest mechanical values of three cook temperatures and lower than controls. Color enhancement was highest for the 230°C cook. Table 1 to 3 present some of the results in an average summary form. Much of the data from these studies is currently being written up in papers for publication so whole data sets are not presented. It is apparent though that the process has not affected mechanical properties. The material tested; however, does not include samples from the 230°C cook as this temperature results in deep colored wood that has greatly reduced mechanical properties as displayed by the brittleness of the wood. Testing of the 230°C cooked Thermowood displayed drastic reductions in mechanical properties similar to those reported by others (Cooper et al. 2007). The 230°C cooked wood will meet the requirements for most applications where this highly decorative wood will be utilized though. Samples for results presented here were taken from 200°C cooked wood as this displays the most attractive coloring for general use and slightly less than, equal to or greater than the controls mechanical properties. Hardness values for Thermowood displayed higher values than the controls and the published values for the given species (Table 1). Densifying of the cell wall will have had an effect on this value as more cell wall substance is contained in a smaller volume than is in the controls, therefore increasing the resistance to denting and increasing the hardness value (see Figure 1). MOE for Thermowood did display slightly lower values than the published values for the species; however they did display higher values than the controls (Table 2). As the values were higher than the controls for the species it seems the process of Thermowood did not actually decrease the MOE value, more the wood growing locally seems to display an MOE value less than the published values for the given species. Nail and screw withdrawal values for Thermowood were also close to or greater than the controls (Table 3). The softwood samples tended to have stronger holding abilities for nails and screws than the controls while hardwoods were the opposite in general. This maybe in part due to the cellular structure of softwoods compared to hardwoods where the strong, thick-walled and evenly aligned radial files of tracheids in softwoods would hold better than hardwoods where there a multiple of cell types including large vessels and thin-walled parenchyma that would not have the holding ability of a tracheid.

Table 1. Average hardness values (Janka Ball Test) for some hardwood and softwood species following treatment in a Thermowood kiln facility.

Species	Hardness (N)	Control (N)	Published (N)
Black Ash	5553	3920	4000
White Birch	4506	3960	4000
Poplar	2049	2400	1600
Tamarack	3520	2223	2600
White pine	2170	2240	1850

Table 2. Average MOE values (3-ptn flexure test) for some hardwood and softwood species following treatment in a Thermowood kiln facility.

Species	MOE (MPa)	Control (MPa)	Published (MPa)
White Pine	7750	6050	8000-9000
White Spruce	7358	5380	9000-10000
Jack Pine	6856	7200	9200-10000
Poplar	7630	5120	8000-10000
White Birch	12210	6070	8000-10000

Table 3. Average Nail and Screw Pull strength for some hardwood and softwood species following treatment in a Thermowood kiln facility.

Species	Nail Pull (Kg)	Control (Kg)	Screw Pull (Kg)	Control (Kg)
White Pine	35.3	27.2	210.2	158.1
White Spruce	43.1	34.6	186.8	189.9
White birch	52.5	88.5	302	345
Poplar	34.8	29.9	187.2	223

Microscopy

A general result from microscopy displays a *collapsing and densifying* of the cell wall. It has also been shown that the hemicellulose component of the cell wall is *degraded* within the cell wall (FTA, 2003). Figures 1 and 2 display the collapsing of cell walls as compared to the cell itself for Black ash and Tamarack; respectively.

Tamarack was not affected as much as Black Ash was by the Thermowood process in terms of colour change. As heat treatment temperatures increased the amount of colouration in the wood in both species is increased. Under the microscope darkening was most evident in the cell walls of ray parenchyma and around vessels in the high temperature cook for Black Ash, although all other fibres were affected as well. At higher temperature cooks there is also the presence of internal checking, a result that has been corrected through tweaking of the recipe for a given species. Softwoods are more prone to the internal checking than hardwoods → special recipes for each species when using the high temperature cooks have been developed. The wood also displays an increase in brittleness in the 230°C cook, which has been reported previously due to a decrease in strength properties at this temperature (Rapp 2001). Brittleness at the highest temperature cook could also be a result of the increase in crystallization in the cellulose of the wood due to the high amounts of moisture used in the Thermowood heat treatment (Bhuiyan *et.al* 1999).

Thermal Characterization

Thermal outputs (calories/gram) for two Thermowood species (Black ash and Tamarack) were conducted using a bomb calorimeter (Parr Instrument 1241 Adiabatic Calorimeter). By using a bomb calorimeter to measure the amount of chemical energy stored in the wood samples it is necessary to know that the energy levels are based on complete combustion of the samples tested. When the samples are ignited within the sealed and pressurized bomb there is no loss of energy and as a consequence the results obtained include all the energy that would usually be lost if the wood was burned in a conventional manner (USDA, 1977). The results clearly display that Thermowood at the highest cook temperature (230°C) resulted in the highest thermal output of 5004 and 5050 calories/gram for black ash and tamarack; respectively, followed by the medium cook temperature (200°C) displaying thermal outputs of 4813 and 4945 calories/gram for Black ash and Tamarack;

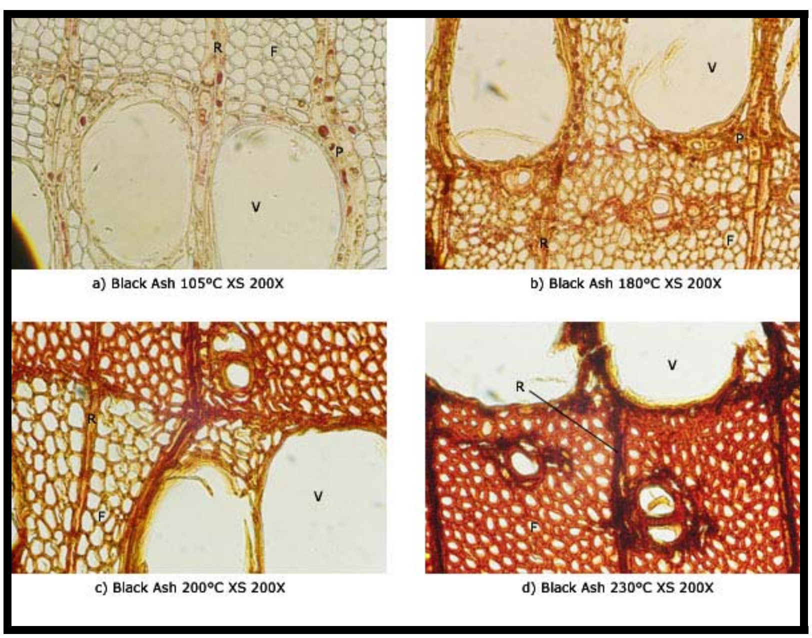

Figure 1: Cross section micrographs of Black Ash at 4 different cook temperatures, V = vessel; P = parenchyma; R = ray; F = fibre.

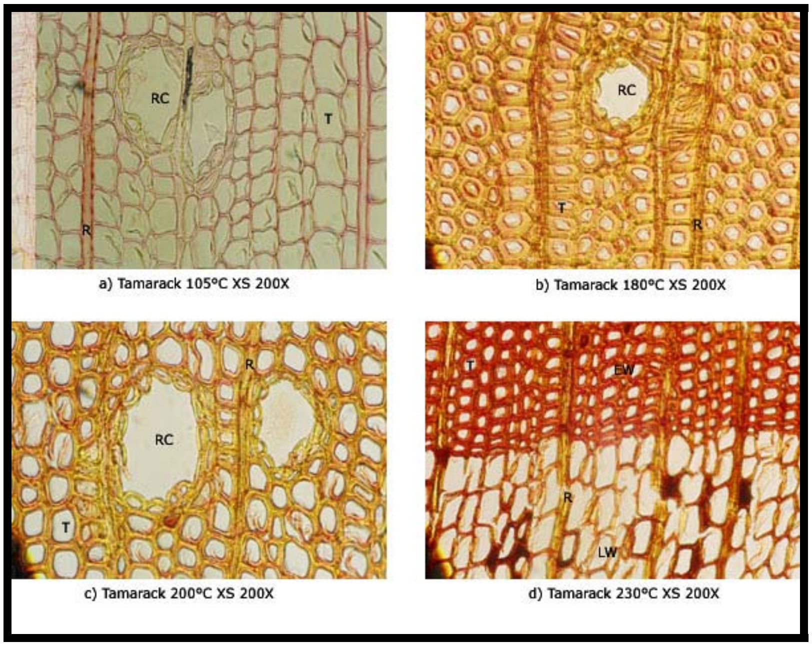

Figure 2: Cross section micrographs of Tamarack at 4 different cook temperatures, T = tracheid; R = ray; RC = resin canal; EW = early wood; LW = late wood.

respectively, then the lowest cook temperature (180°C) resulted in thermal outputs of 4658 and 4857 calories/gram for Black ash and Tamarack; respectively, and the lowest thermal outputs by the standard kiln cook temperature (105°C) where values of 4612 and 4617 calories/gram for Black ash and Tamarack; respectively (Table 4). Medium and high temperature cooks displayed significantly higher values than the control (standard kiln cook) and low temperature cook. The low temperature cook was not significantly different than the control. One explanation for the Tamarack displaying more chemical energy is softwoods tend to burn hotter than hardwoods due to their higher carbon content (Baker, 1983). It can also be seen in Table 4 that Black ash displays a higher variance than tamarack, particularly for the natural controls. This can be explained in part by the fact that Thermowood has very low and consistent moisture contents (Rapp, 2001) compared to the natural controls. Also Black ash displayed more variance than Tamarack, which can be explained to a large degree by the ring porous nature of Black ash (Farrar, 2000) and therefore has more variation in density across growth rings (Hoadley, 1990). Depending on the location that samples were ground from there is the potential that more earlywood was in the sample than latewood resulting in a higher percentage of thinner-walled vessels compared to thick-walled fibers of the Black ash wood. Tamarack on the other hand is composed almost entirely of tracheids (Hoadley, 1990).

This result clearly displays that the Thermowood waste has potential in the bio-product arena, particularly in the bio-energy arena through pellet production.

Table 4. Summarized group means and statistical parameters of each sample group tested (BA – Black ash, LA – Tamarack, NAT – natural controls, LOW – 180°C temp. cook, MED – 200°C temp. cook, 230°C High temp. cook).

Sample Description	Group Mean (Calories / g)	Standard Deviation	Variance
BA NAT	4612.34	102.28	10462.18
BA LOW	4658.63	25.83	667.21
BA MED	4813.38	39.85	1588.02
BA HIGH	5004.63	40.97	1678.53
LA NAT	4617.81	42.84	1835.66
LA LOW	4857.54	25.42	646.26
LA MED	4945.25	25.41	645.49
LA HIGH	5050.03	40.76	1661.20

4. Conclusions

It is obvious this fairly new process has a wide variety of end product potential. Particularly utilizing under-utilized species, allowing entry to markets not available previously. Product properties are particularly good for certain products, with some variation in the cook settings to allow different end product properties within a species.

A clean alternative to chemically treated wood products while increasing the aesthetic appearance of many species through deepening of the color. Increased dimensional stability will render this product very attractive to flooring manufactures as well as furniture makers. In the area of value-adding there is potential to increase, significantly, the manufacturing of furniture, flooring and other products that will benefit from the deep attractive colors this process produces in wood.

Increases in thermal values has potential for waste products of Thermowood to be utilized in the bio-product area where increased thermal values will be seen as a very positive feature, particularly in the manufacturing of pellets.

The benefits of high temperature *Thermowood* kilns are apparent, as is the potential in the value-adding sector. Future development of this technology will no doubt increase opportunities in the forest sector in Canada.

5. Acknowledgements

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