Effect of High Temperature on Wood Properties of Canadian Boreal Hardwood Species: Case Study of Black Ash from northwestern Ontario

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Abstract

Thermally modifying wood originated in the early 1990's in Finland. The process involves cooking wood at high temperatures for relatively short durations. The end result is an aesthetically pleasing wood with much better properties. The objective of this paper is to present results on the effect of Thermowood treatment on physical, mechanical, and thermal properties of a Canadian Boreal hardwood species. Defect-free samples of Thermowood black ash (*Fraxinus nigra* Marsh.) were collected following runs in a new high temperature kiln system being developed in northwestern Ontario, Canada by Superior Thermowood®. As an under-valued and under-utilized tree in Canada, this species was selected as one, which could benefit from a new high temperature kiln process. During the high temperature runs (200°C wood temperature), the wood deepened in color from a light brown to a darker brown similar to that of walnut wood and displayed an increase in hardness compared to the controls as well as the published values for this species. Using the Janka Ball Hardness test, thermally modified black ash displayed average hardness values of 5670N at 8% moisture content (MC), which were 31% greater than the controls (3965N) and 33% greater than published values (3800N at 12% MC). When values were corrected to 12% MC, the thermally modified black ash displayed an average hardness value of 3968N while the controls were 2816N. Compared to the published values the thermally modified black ash corrected to 12% MC is still slightly higher in hardness than the published values for the species and well above the locally grown species values. Hardness values for control black ash samples from northern Ontario were around 6% greater than the average published values. Microscopy confirmed the modifications to the cell wall structure as being densified, which lead to a side study to test the British Thermal Unit (BTU) output of Thermowood waste on a bomb calorimeter. It was realized that the BTU output of controls materials was 4600 calories /gram while the high temperature Thermowood run (230°C) resulted in a BTU output of 5000 calories/gram. With an improvement in the woods aesthetic appearance combined with the slight increase in hardness and thermal output, this species is well suited to be utilized in high-value markets including flooring and fine furniture with the waste stream displaying opportunities in the pellet industry as an additive. A brief market study of the flooring industry was conducted to recognize the potential of products such as Superior Thermowood Black Ash flooring in the market place.

Keywords: thermally modified wood, Janka Ball Hardness Test, BTU, under-valued and -utilized species, value-adding, black ash, Boreal hardwoods.

INTRODUCTION

A key indicator of wood quality is the amount of cell wall material present in a cell and how those cells are arranged in relation to one another. The amount of cell wall material is a general indicator of the density of wood (Panshin and DeZeeuw 1980, Zobel and Talbert 1984). Density regulates in many respects the mechanical properties of a wood (Desch and Dinwoodie 1981, Garratt 1931, Porter 1981). Some properties such as flexure are better suited to the long, more flexible tracheids of softwoods while hardness is better suited to the short, but very dense fibers of hardwoods.

When considering hardness as a key indicator for end-use products such as flooring it is necessary to utilize woods that display a high value for this purpose. Higher density woods typically display higher mechanical property values (Herajarvi 2004), particularly hardness values; for example Balsa wood has a density around 160 kg/m^3 (Desch and Dinwoodie 1981) and displays extremely low strength properties while a species such as hard maple has a density around 700kg/m^3 (Panshin and DeZeeuw 1980) and displays extremely high strength properties (Burrows 2000). Hardness is defined as the ability of the material to resist an intrusion by an object that is external to the material (Herajarvi 2006). More simply put it is the resistance of a material to indentation (Garratt 1931).

The hardness value derived from the Janka ball test is evaluated against hardness data from various sources for the same species and other comparative species. Table 1 lists the hardness values of various species from Green *et al.* (1999) and from Kennedy (1965) that are comparable to species grown in Northern Ontario used for flooring, paneling, decks, furniture and dimensional lumber (Trembling aspen is included as an example low density hardwood found in Northern Ontario).

Black ash (*Fraxinus nigra* Marsh.) is a hardwood species growing across Ontario and to the east coast of Canada (Hosie 1979). It is an under-valued and under-utilized species and has been referred to as a substitute for white oak as it has very similar aesthetic features except for the large rays the oaks display. Color is similar and both are ring porous species displaying this feature on all cut planes. Black ash has typically been used by first nation peoples for baskets, snowshoes and other products (Elias 1980, Peattie 1950) and commercially on a limited scale for interior finish, cabinetwork and fixtures (McElhanney 1951). Currently red oak and hard maple are the most commonly used hardwood species (Beaulieu 2003) in the United States. More recently black ash is used for flooring and furniture with the main use being flooring. The potential for this species in a value-added market has made this species very attractive to small manufacturers. In particular Superior Thermowood® is utilizing black ash in their high temperature Thermowood kilns to add value and have this recognized as a high value species. In a traditional kiln the operating wood temperature is roughly 105°C for an extended period of time, generally several weeks. In a Thermowood kiln the operating wood temperature is between 180°C and 230°C for a set time following a ramping up schedule. Subsequent to the top temperature period there is a cool down phase after which time the run is complete, generally occurring in 36 hours or less from green down to a final moisture content of 5 – 8% (Finnish Thermowood Association 2003). In addition to attaining a low final moisture content the process promotes the deepening of the woods color from a very pale to that of black walnut depending on the run temperature. The ability of the process to add value to under-valued species through color is a positive step for the value-adding industry in Canada; however, there is also the additional advantage of physical changes to the wood that improve certain properties for specific end use products. For example, a light colored wood, such as black ash or poplar, can have its color enhanced for use in flooring or cabinetry when it may not otherwise be utilized for this product. The process is also useful for production of outdoor products due to increased moisture and fungal resistance, which will be addressed in a subsequent paper dealing with softwood species and the Superior Thermowood® process.

This paper presents results of investigations measuring the hardness values of Superior Thermowood® black ash using the Janka ball hardness method. A brief look at markets for solid wood flooring was also investigated to elucidate trends in the flooring industry that has been evolving with the introduction of engineered floors.

MATERIALS AND METHODS

Selection of Wood Samples

Sample material

All black ash sample material was provided by Superior Thermowood® (Kakabeka Falls, Ontario, Canada) following a 200°C treatment in their kiln. Samples arrived as 2.5cm thick x 15cm wide x 240cm long rough sawn boards at a moisture content (MC) of between 5 and 8%. 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 and left 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 in the Lakehead University Wood Science and Testing Facility. Initially the boards were tested for moisture content to ensure all were at the 5-8% level using an electronic moisture meter (Protimeter – *Surveymaster*) and confirmed using weight at testing and then again at bone dry to calculate MC. Following this all boards were put through a planer to clean both the top and bottom surface. Board surfaces were then marked and labeled along their length for individual samples. Four samples were collected at each end and four in the middle of the board. Similar samples were collected from control boards that were removed from the stack prior to processing. Controls were dried to a MC of 8% in an oven at 65°C until the desired MC was attained. All tests samples had a final dimension of 2.5cm thick x 7.5cm wide x 10cm long (maximum thickness attainable due to sample boards arriving as raw flooring). For this study 168 samples were prepared for hardness testing.

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) and operated through a computer running Test Navigator Software. The load to imbed the ball was applied at a rate of 8mm/minute and results were recorded in Newton's (N). Face hardness (equal number of radial and tangential surfaces) was measured on all samples. Sample moisture contents were checked again prior to testing ensuring they were between 5 and 8%. Following all tests the data were corrected to 12% MC using the conversion equation presented in the Wood Handbook (Green *et al.* 1999).

Market Analysis

A simple market investigation was conducted to look at where the flooring industry is now and where trends are heading with respect to hardwood flooring products.

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. A T-test at the 95% C.I. was also conducted to compare the STW black Ash to the controls.

RESULTS

Thermowood treatment of black ash resulted in all samples deepening in color from a light brown to a darker brown similar to that of walnut wood. There was an increase in hardness (Janka Ball Test) values compared to the controls as well as the published material for both kiln runs (referred to as Run A and B) tested (Table 2). Both kiln runs produced, on average, similar results to one another with Run A displaying an average of 5310 N and Run B displaying an average of 6110 N (Table 2, 8% MC values). There was some variation seen between boards within a run; however, the lowest values of the Thermowood black ash were greater than the average control and published values. For Run A and B combined (at 8% MC), thermally modified black ash displayed average hardness values (5670N, 8%) 31% greater than the controls (3965N, 8%) and 33% greater than published values (3800 -4200N, 12% MC). When values were corrected to 12% MC the thermally modified black ash displayed an average hardness value of 3968N while the controls were 2816N (Table 2). Compared to the published values the thermally modified black ash corrected to 12% MC is slightly lower in hardness than the published values by Kennedy (1965); however, they were slightly higher than the published values by Green *et al.* (1999) for the species and well above the locally grown species values. The results display that thermally modified Northern Ontario black ash is harder than the published values for this species and much harder than the controls. It is also apparent that the Thermowood process appears to improve aesthetic and hardness properties of black ash making this an ideal species in a value-added industry in northern Ontario.

Market investigation displayed there is a strong market for quality hardwood flooring and this is expanding as people move from carpets to wood floors. In the early 1990's carpets captured 71% of the market compared to other flooring products, while in 2002 carpets captured 65% of the market share. One trend is that engineered hardwood floors are taking a large percent of the hardwood flooring market. This trend has been increasing over the last 20 years when solid wood floors had over 70% of the hardwood flooring market compared to 30% engineered, while in 2002 engineered hardwood floors captured 58% of the market compared to 42% for solid wood. Engineered hardwood flooring is more popular in Europe than NA.

DISCUSSION

Strength of a wood is the capability of the wood to bear load without being deformed (Bowyer *et al.* 2003). Mechanical properties of wood define the relationship between the load and deformation of wood. The hardness of wood reflects its durability (Bowyer *et al.* 2003) and is a property tested commonly on woods used for paneling, furniture, flooring, decking etc. that demand the wood to be resistant to indentations. Hardness values are typically measured at green and 12% MC (Green *et al.* 1999); however, in this study all Thermowood samples were at 5-8% MC as this is the condition the wood is in when it completes a run and controls were also dried to 8%. Typically mechanical properties increase as wood dries (Garratt 1931, Green *et al.* 1999) so it is expected that the values attained at 5-8% MC may be slightly higher than the published values at 12% MC; however, the controls were dried to a MC of 5-8% for consistency and the treatment samples still exceeded the hardness values significantly when compared to the controls. When the results were corrected to 12% MC the STW black ash still exceeded the published hardness values for the species slightly and exceeded the control values significantly. The STW black ash will however, be utilized at the 8% MC level in products making this hardness value more meaningful to the end user. In Table 1 it is apparent that location affects hardness, as Green *et al.* (1999) values recorded in the US are lower than those recorded by Kennedy (1965) in Canada. Variations within the current tests are likely due to the intensity of the thermal treatment and also the growth rate of the samples. The intensity of the thermal treatment can vary depending on initial moisture content, amount of knots, amount of juvenile compared to mature wood, any grain deviations, and the presence of reaction wood for example (see Desch and Dinwoodie 1981, Garratt 1931, Green *et al.* 1999). Black ash is also a very attractive wood due to the effect of knots on the grain. These knots will also affect hardness values (Green *et al.* 1999) in a localized manner as will the grain that is affected by the knot itself. In the current study knots were excluded from samples; however, the effect of a knot on the grain may affect other parts of the plank near the knot. Juvenile wood compared to mature wood displays lower hardness values due to cell wall characteristics in juvenile compared to mature wood. The main characteristic that would affect hardness is the lower amount of cell wall material in juvenile wood and the alignment of microfibrils in the secondary cell wall layers decreasing the resistance of penetration compared to mature wood. Grain is also affected by which plane is tested. For this study both tangential and radial planes were tested and the final values are averages for all tests. The plane tested may have an effect on values particularly when growth rate is considered. Growth rate can drastically affect the treatment process in an individual plank compared to another due to the amount of wood produced in a given year and how the cells are arranged. Typically a tree growing quickly will produce wood of lower density than a tree growing slowly (Garratt 1931) due to the amount of cell wall material produced. This generalization does not apply to ring porous hardwoods though due to the band of large vessels produced early in the year. When growth is accelerated in ring porous woods there is more high-density latewood fibres formed compared to the low-density earlywood vessels. It has been stated that the proportion of earlywood vessels in ring porous woods does not usually increase with an increase in ring width (Garratt 1931). Therefore, in ring porous hardwoods, the faster the growth and wider the growth rings the heavier, harder, stronger and stiffer the wood will be (Garratt 1931). A last point to make regarding variation is the age of the tree. Young trees contain more juvenile wood displaying inferior and inconsistent properties (Bowyer *et al.* 2003) while older trees contain more mature wood that displays superior and consistent properties (see Green *et al.* 1999, McAlister and Clark 1991). Radial and longitudinal variation in wood properties is recognized (Keith and Kellog 1981) and cannot be controlled for the most part. The consistency of mature wood, as you get further from the pith, is recognized and suggests larger diameter trees are more suitable for sawn lumber products. For these reasons some variation in the results can be expected; however, these variations would have been present during the testing for the published values so on average the Superior Thermowood® values are significantly higher than this species in northern Ontario can produce without this process.

Market investigation displayed that hardwood flooring still has a strong market opportunity. Engineered hardwood floors have made a great leap since their introduction into the market place. This is likely due to the cost of the product and ease of installation. Engineered floors are a fraction of the cost of solid hardwood floors making them more attractive in prebuilt homes and also as a means of replacing old carpets at a reasonable price. The snap installation floors are also very easy to install making them more attractive to home renovators.

CONCLUSION

It is apparent that black ash growing in northern Ontario displays properties that render it an appropriate species for value-adding and high-value forest products following a thermowood treatment, such as solid wood flooring. Once hardness values were corrected to 12% MC the STW Black ash displayed properties similar to the published values and significantly higher than the controls. The STW process, located in Kakabeka, Ontario, does not reduce the hardness values of this species nor does it decrease properties as is reported for several of the other Thermowood processes on the market (Finnish Thermowood Association, 2003). The product will be in service at the 8% MC level meaning its properties at this MC are even better for the products mentioned. The combination of improved properties and aesthetics suggests this species is well positioned to help increase secondary processing facilities in Canada and in particular in northern Ontario. Black ash is very similar to white oak in appearance making it an obvious choice for flooring and furniture manufacturing, particularly when the aesthetic improvements place the wood in a color category with walnut and mahogany. The color enhancement is one feature that will greatly increase the potential value of products following the Thermowood treatment. Market investigation also suggests this is a product (flooring) where demand is increasing as carpet is losing market share. Even though engineered wood flooring is increasing its market share, solid wood flooring still holds a good portion of the market. In northern Ontario and other provinces thermowood technology could provide opportunities that would otherwise not be available.

ACKNOWLEDGMENTS

I would like to acknowledge Superior Thermowood® and in particular Ed Rose for continually supporting my research program and working with Lakehead University. I would also like to acknowledge FedNor, NOHFC, OMNR and Living Legacy Trust for funding for this project.

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Table 1. Published hardness values (N) for several hardwood species as compared to Black ash (Green *et al*. 1999, Kennedy 1965).

Species	Hardness values (N) Green *et al.* 1999	Hardness values (N) Kennedy 1965
Trembling aspen	1600	2144
Black ash	3800	4216
White ash	5900	7054
Yellow birch	5600	5925
White birch	4000	4323
White oak	6000	7126
Northern Red oak	5700	6183
Sugar maple	6400	7286

Table 2. Janka ball hardness values (N, at 8% MC and corrected to 12% MC) for Superior Thermowood® Black ash, including control and published values (standard deviation in brackets).

Sample	n	Mean	Hardness Value (8% MC)	Hardness Value corrected to 12% MC
Run A	72	5120 (1487)	5310	3727
Run B	60	6110 (1188)	6110	4263
Run A & Run B	132	5760 (1412)	5670	3968
Control	36	3680 (1876)	3965	2816
Published*	N/A	N/A N/A	N/A	3800*

*Green *et al.* 1999