HARDNESS VALUES FOR THERMALLY TREATED BLACK ASH

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Abstract. The objective of this study was to analyze the effect of a thermal treatment on the hardness of a Boreal hardwood species. As an undervalued and underutilized tree in Canada, black ash (*Fraxinus nigra* Marsh.) was selected as one that could potentially benefit from this process. The wood was processed runs in a new high-temperature kiln system being developed in northwestern Ontario, Canada, by Superior Thermowood®. During the processing, the wood deepened in color from a light brown to a darker brown, similar to that of walnut wood. Defect-free samples of Thermowood black ash were collected from two high-temperature runs (200°C wood temperature) and tested for hardness. Using the Janka ball hardness test, thermally modified black ash displayed average hardness values at 8% MC (5700 N), 43% greater than the controls and in the same range as published for untreated wood (5400 – 6000 N). With an improvement in the black ash aesthetic appearance combined with the slight increase in hardness, this species is well suited to be utilized in high-value markets, including flooring and fine furniture.

Keywords: Thermally modified wood, thermowood, Janka ball hardness test, undervalued, underutilized, value-adding, black ash.

INTRODUCTION

Wood quality is generally characterized based on some specific properties, particularly those that enable it to be utilized in an end-use product. A key indicator of wood quality is the amount of cell wall material 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, which usually is calculated using a dry weight value and the sample volume (Panshin and DeZeeuw 1980; Zobel and Talbert 1984). Density regulates in many respects the mechanical properties (Garratt 1931; Desch and Dinwoodie 1981; Porter 1981), which is variable depending on the property being measured. Some properties such as flexure are enhanced by the long, more flexible tracheids of softwoods, whereas hardness is an attribute of the short and 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 have a high value. Higher density woods typically have higher mechanical property values (Heräjärvi 2004), particularly hardness values. For example, balsa wood with a density about 160 kg/m^3 (Desch and Dinwoodie 1981) has extremely low strength properties, whereas hard maple with a density about 700 kg/m^3 (Panshin and DeZeeuw 1980) has very high strength properties (Burrows 2000). The higher density of hard maple is one reason it is utilized for flooring, bowling alley floors, and other uses where a very hard, dent-resistant surface is required (Burrows 2000). Hardness is defined in a variety of ways; however, Heräjärvi (2004) summarized hardness of a material as the ability to resist an intrusion by an object that is external to the material. More simply put, it is the resistance of a material to indentation (Garratt 1931). Hardness was also described by Lassila (in Heräajärvi 2004) to be dependent on the

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amount of force used, the species, the structure of the wood, surface plane tested, MC, wood temperature, and the weight of the wood. Garratt (1931) also stressed wood structure as a determining factor for hardness and, in particular, fiber size, cohesion, and arrangement.

The hardness value derived from the Janka ball test is meaningless unless it is evaluated against hardness data from various sources for the same and comparable species. Table 1 lists the hardness and specific gravity values of various species from Green et al (1999) and Kennedy (1965) that are comparable to species grown in northern Ontario and used for flooring, paneling, decks, furniture, and dimensional lumber. Trembling aspen is included as an example of a low-density and low-hardness species. The hardness values listed for Kennedy (1965) are from trees grown and sampled in Canada.

Black ash (*Fraxinus nigra* Marsh.) is a hardwood species growing across Ontario to the Canadian east coast (Hosie 1979). It is an undervalued and underutilized species and has been referred to as a substitute for white oak because it has very similar aesthetic features except for the large rays of oak. Color is similar and both are ring-porous species displaying this feature on all cut planes. Black ash has typically been used by First Nations peoples for baskets, snowshoes, and other products (Peattie 1950; Elias 1980) and on a limited commercial scale for interior finish, cabinetwork, and fixtures (McElhanney 1951). Currently red oak and hard maple are the most commonly used hardwood species) in the United States (Beaulieu 2003).

Table 1. *Published hardness (N) and (specific gravity) values for several hardwood species as compared with black ash.*

Species	Green et al (1999)	Kennedy (1965)
Trembling aspen	1600 (0.370)	2100 (0.410)
Black ash	3800 (0.490)	4200 (0.490)
White ash	5900 (0.600)	7100 (0.610)
Yellow birch	5600 (0.620)	5900 (0.610)
White birch	4000 (0.550)	4300 (0.570)
White oak	6000 (0.680)	7100 (0.680)
Northern Red oak	5700 (0.630)	6200 (0.610)
Sugar maple	6400 (0.630)	7300 (0.660)

More recently, black ash has been used for flooring and furniture, with the main use in flooring. The potential for this species in a value-added market has made it very attractive to small manufacturers.

In particular, Superior Thermowood® is processing black ash in their high-temperature Thermowood kilns to add value and have it recognized as a high-value species. The process of Thermowood is one that has been around since the early 1990s, originating in Finland and now present in several European countries (Finnish Thermowood Association 2003). The process is an adaptation of a traditional kiln system with the main difference in the operating temperature. In hardwood drying with a traditional kiln, the maximum operating wood temperature is about 80°C in the final portion of the schedule for several weeks. In a Thermowood kiln, the operating wood temperature is 180 – 230°C for a set period after a ramping-up schedule. A typical run is 36 h or less from green down to a final MC of 5 – 8% (Finnish Thermowood Association 2003) followed by a cooling phase. In addition to attaining a low final MC, the process promotes the deepening of the wood color; for example, poplar, a very pale wood, can be changed to mimic black walnut at the medium or top temperatures (ie 200 or 230°C, respectively). The ability of the process to add value to undervalued 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 used. The process is also useful for production of outdoor products from increased moisture and fungal resistance, which will be addressed in a subsequent paper dealing with softwood species and the Superior Thermowood® process.

This article presents results of investigations measuring the hardness values of Superior Thermowood® (STW) black ash using the Janka ball hardness method.

MATERIALS AND METHODS

Selection and Preparation of Wood Samples

Sample material. All black ash sample material was provided by Superior Thermowood® (Kakabeka Falls, Ontario, Canada) after a 200°C wood-temperature treatment in their kiln. Temperature was monitored with sensors placed in the wood during the kiln run. Samples arrived as 25-mm-thick × 150-mm-wide × 2.4-m-long rough-sawn boards at MC of 5 – 8%. Boards were selected from the kiln with 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. Within the sample boards, an equal number of boards was selected with tangential and radial faces so that the results represented both planes. All sample pieces were defect-free and as straight-grained as possible.

Sample preparation. STW **s**amples were prepared in the Lakehead University Wood Science and Testing Facility. Initially the boards were tested to ensure all were at 5 – 8% MC using a Protimeter (Surveymaster) moisture meter and confirmed using weight at testing and then again at oven-dry. Specific gravity was also determined from oven-dry samples using the water displacement method. Boards were then planed to clean the top and bottom surfaces. Board surfaces were marked and labeled along their length for individual samples. 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 inward. Middle samples were collected by removing two samples from each side of the exact center of the board. Similar samples were collected from control boards that were removed from the stack before processing. Controls were dried in an oven at 65°C until 8% MC was attained. All tests samples had final dimensions of 25 mm thick × 75 mm wide × 100 mm long. Although ASTM (2005) prescribes 50-mm thickness for hardness testing, the thickness of the available boards was limited at 25 mm. However, according to Green et al (2006), hardness values are independent of thickness over 25 – 75 mm. For this study, a total of 168 samples were prepared for hardness testing.

Testing Conditions and Assessment

All tests were performed on a Tinius Olsen H10KT Universal Testing Machine equipped with a Janka ball hardness testing tool (11.3-mm-dia ball) and operated with a computer running Test Navigator Software. The load to imbed the ball was applied at a rate of 8 mm/min. The run was ended when the collar around the ball tightened against the wood sample. Face hardness (equal number of radial and tangential surfaces) was measured on all samples ensuring tests were far enough from edges to prevent splitting. Samples were rechecked before testing to ensure they were 5 – 8% MC. After all tests, the data were corrected to 12% MC using the conversion equation presented in the Wood Handbook (Green et al 1999).

All results produced through the Test Navigator Software included average, COV, standard deviation as well as limits. Comparisons were made between controls, published values, and the results presented here. A *t* test at the 95% CI was also conducted to compare the STW black ash with controls.

RESULTS

The treatment of STW black ash caused all samples to deepen in color from a light to a darker brown, similar to that of walnut wood. There was an increase in hardness (Janka ball test) values compared with the controls as well as the published material for both kiln runs (Runs A and B) (Table 2). It is apparent that the specific gravity of black ash is fairly consistent between published values at about 0.490 (see Table 1), whereas the material tested in this study showed an average value of 0.580. Both kiln runs produced similar average results with Run A having an average of 5300 N and Run B, 6100 N (Table 2; 8% MC). There was some variation between boards within a run; however,

Table 2. *Janka ball hardness values (N, at test, corrected to 8% MC and 12% MC) for Superior Thermowood® black ash, including control and published values.*

Sample	n	Mean (SD) Test MC	8% MC	12% MC
Run A	72	5100 (1500)	5300	3700
Run B	60	6100 (1200)	6100	4300
Run A and B	132	5800 (1400)	5700	4000
Control	36	3700 (1900)	4000	2800
Published[a]	—	—	5400 – 6000	3800 – 4200

[a]Kennedy 1965; Green et al 1999.

the lowest values of the STW black ash were greater than the average control and published values. For Run A and B combined (at 8% MC), the STW black ash had average hardness values (5700 N, 8% MC) 31% greater than the controls (4000 N, 8% MC) and 33% greater than published values (3800 – 4200 N, 12% MC). When values were corrected to 12% MC, the thermally modified black ash had an average hardness value of 4000 N, whereas the controls were 2800 N (Table 2). Compared with the published values, the thermally modified black ash corrected to 12% MC is similar in hardness to the published values (Green et al 1999; Kennedy 1965) and well above the locally grown species values. 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.

DISCUSSION

Strength of wood is the capability to bear load without being deformed (Bowyer et al 2003). Mechanical properties of wood define the relationship between the load and deformation of wood (Logan 1991). The hardness of wood reflects its durability (Bowyer et al 2003) and is a property commonly tested on woods used for paneling, furniture, flooring, decking, and so on, that requires the wood to be resistant to indentation. Hardness values are typically measured at green and 12% MC (Green et al 1999); however, in this study, all Thermowood samples were 5 – 8% MC because this was the condition of the wood when the run was completed and controls were also dried to 8% MC. Typically, mechanical properties increase as wood dries (Garratt 1931; Green et al 1999); therefore, it is expected that the values attained at 5 – 8% MC may be somewhat higher than those published at 12% MC; however, the controls were dried to a MC of 5 – 8% for consistency and the treatment samples still significantly exceeded the hardness values compared with the controls. When the results were corrected to 12% MC, the Thermowood black ash was similar to the published hardness values. The STW black ash will be used at the 8% MC level making this hardness value more meaningful to the end user. Using the Janka ball test, it was shown that northern Ontario black ash has lower hardness values than that published for this species. It was also realized that the Thermowood treatment increases the hardness value of the species when compared with the controls. Poncsak et al (2006) and LiShi et al (2007) found similar results for thermally modified white birch at similar kiln temperatures. Microscopic examinations confirm the cell wall compresses and becomes denser (to be submitted in a subsequent paper). This in part explains much of the increase in hardness values seen for this species when compared with published values. In Table 1, it is apparent that geographical location affects hardness, because Green et al (1999) values recorded for the United States are lower than those by Kennedy (1965) for Canada. Interestingly, the specific gravity values of the published values are all within 0.004, although hardness values vary between these publications, whereas the tested material had a specific gravity of 0.580. Without more information on the sample trees, it is difficult to ascertain the reason for the difference, particularly when noting that the specific gravity values are very similar between published values.

Variations within the current tests are likely from the intensity of the thermal treatment and the growth rate of the samples. The intensity of the thermal treatment can vary depending on initial MC, number and size of knots, amount of juvenile compared with mature wood, grain deviation, and the presence of reaction wood (Garratt 1931; Green et al 1999; Desch and Dinwoodie 1981). These variations in a board can slow the treatment process meaning the board may be somewhat lighter in color and hence slightly lower in hardness. Alternatively, if the board is lower in density than others, it may come out darker having a lower hardness value from an increase in brittleness. This could help explain the variation that we see in the reported specific gravity values that are not apparent in the hardness values.

Black ash is also a very attractive wood from the effect of knots on the grain. Knots also affect hardness values (Green et al 2006) 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 board near the knot. These areas may have been used in test samples if the grain deviation was not noted on the surface. Juvenile compared with mature wood has lower hardness values from cell wall characteristics. 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 decreasing the resistance of penetration compared with mature wood. Spiral grain was not permitted in samples, although minor grain deviations from vertical are common in this species and were in most samples. Sloping grain has been shown to affect strength properties negatively (Desch and Dinwoodie 1981; Bowyer et al 2003; ASTM 2005). 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 board compared with another from 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) from the amount of cell wall material produced. This generalization does not apply to ring-porous hardwoods from the band of large vessels produced early in the year. When growth is accelerated in ring-porous woods, there is more high-density latewood fibers formed compared with 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). Hirata et al (2001) developed a hand-operated hardness tester to measure the variation between earlywood and latewood density within a growth ring and found the earlywood to be less dense than the latewood in the same growth ring. 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), whereas older trees contain more mature wood that displays superior and consistent properties (McAlister and Clark 1991; Green et al 1999). Radial and longitudinal variation in wood properties is recognized (Keith and Kellogg 1981) and is relatively uncontrollable. The consistency of mature wood, with distance from the pith, is recognized and suggests larger diameter trees are more suitable for 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. Therefore, on average, the STW values are significantly higher than this species can produce in northern Ontario without this process.

CONCLUSIONS

It is apparent that black ash growing in northern Ontario displays properties after a thermal treatment that renders it an appropriate species for value-added and high-value forest products. Such products include solid wood flooring, specialty items, and fine furniture. Once hardness values were corrected to 12% MC, STW black ash had properties similar to published values and significantly higher than the controls. This shows that the process does not reduce the hardness values of this species and also that the particular process at Kakabeka, Ontario, is modified so that it does not reduce properties as reported for several other Thermowood processes (Finnish Thermowood Association 2003). It should also be noted that the product will be in service at 8% MC making its properties even better, particularly for flooring in which the increased hardness will benefit the final product. The combination of improved properties and aesthetics through the Thermowood® process suggests this species is well positioned to become part of a surge to increase secondary processing facilities in Canada, and in particular in northern Ontario, where the forest industry has been struggling recently from a reliance on commodity products. 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. Value-adding is a direction that part of the forest industry is heading, and in northern Ontario and other provinces, this type of technology could provide opportunities that would otherwise not be available.

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