COMPARING BIRCH CORE PLYWOOD WITH TRADITIONAL SOFTWOOD PLYWOOD

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April 8, 2020

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An Undergraduate Thesis Submitted in

Partial Fulfillment of the Requirements for the

Degree of Honours Bachelor of Science in Forestry

Faculty of Natural Resources Management

Lakehead University

April 2020

Major Advisor | Second Reader

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ABSTRACT

Huitema, T.M. 2019. Comparing Birch Core Plywood with Traditional Softwood Plywood.

Key Words: birch plywood, birch core, plywood, property testing, modulus of elasticity, compression, hardness, plywood market

Plywood made with birch cores is an important product in the European Union, and has potential to become an important product in North America. White birch in Ontario is currently an underutilized species. This paper explores the mechanical properties of a new plywood product being produced in Ontario that is very similar to European birch plywood, but uses white birch (*Betula papyrifera*) grown in North America. Tests were done to measure the modulus of elasticity, compressive strength parallel to the grain and hardness of the new plywood and traditional softwood plywood. These values were tested using the ASTM D1037-12 testing standard. Compared to softwood plywood, the birch plywood had 94.83% of the compressive strength of softwood plywood, 82% of the MOE and 181.95% of the hardness.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Dr. Mathew Leitch with his guidance and interest in this project and Rob Glover for his assistance in the LU Wood Science and Testing Facility. I would also like to acknowledge Dan Bowes of Columbia Forest Products for taking time to help me with this project and providing me with materials for testing.

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Introduction and Objective

White birch (*Betula papyrifera*) is an abundant species in the boreal forest of Canada (National Forest Inventory 2016), and often goes underutilized as a forest resource. Birch plywood (often called Baltic birch) is a product produced by manufacturers in Europe out of the native European Birch (*Betula pendula*) and is used for specialty applications like furniture and cabinetry. Its sturdiness and highly attractive appearance make it popular in both Europe and North America, where it is commonly imported (LeGros 2019). Since North American birch is underutilized, and there is a market in North America for manufactured birch plywood, it is worth exploring whether it is economical to produce it domestically, from native birch. The purpose of this thesis is to test the properties of a new plywood product made from North American white birch and compare it to softwood plywood to gauge whether or not it can be used in the same applications. According to the Wood Database (n.d.), European birch, as solid wood, has a higher density as well as MOE and MOR than its North American counterpart , so it can be assumed that it will have higher strength properties when manufactured into plywood, however ply size, number of plies and the nature of the glue used (Okuma 1976)will influence this outcome.

American Society for Testing Material (ASTM) is an international standard for testing material properties. It is important to use a standard testing method so that replications can be made anywhere in the world and can accurately be used for comparison. The testing will be done at the Lakehead University Wood Science Testing Laboratory and will conform to these standards when testing all the types of plywood.

1.2 OBJECTIVE

The objective of this thesis is to test a plywood product made from North American white birch and compare it to softwood plywood. By comparing it to softwood plywood, the possibility of it being used as an alternative to softwood panels in an effort to utilize more birch can be discussed.

1.3 HYPOTHESIS

Plywood made from North American white birch will have better strength properties (MOE, MOR, hardness, compression strength) than traditional softwood plywood.

Literature Review

History of Plywood

The roots of plywood go back thousands of years. The ancient Chinese used shaved wood to build furniture and ancient Egyptian pharaohs have traces of laminated wood in their tombs. 17^{th} and 18^{th} century French and British builders also used something like plywood (Engineered Wood Association n.d.). Plywood as we know it now, however, did not start mass manufacturing until the mid 19^{th} century. John K. Mayo of New York City obtained a patent in 1865 for scales or sheets of wood cemented together running crosswise from the others. He was not able to successfully market the product however (Morris 2017). Commercial interest in plywood didn’t start until the 1905 World’s Fair in Portland, Oregon. The owner of a local box making factory, Gustav Carlson, was told to make something creative for the upcoming World’s Fair, so he made a plywood with 3 cross laminated veneers of three northwest softwood species. This product was made with crude methods including a homemade wooden press, charcoal fire, and glue that smelled so bad that workers had to seek comfort outside (Plywood Pioneer's Association 1967). Some door manufacturers that attended the fair were very interested in his product, and placed orders for some full sheets. And thus, mass production of plywood began. By World War 2, plywood was so popular it became designated as an essential war material, and it was used in everything from small plywood boats to barracks and crating for food and ammunition (Plywood Pioneer's Association 1967). Up until this time, plywood production was centred in the Pacific Northwest, where industrialists could take advantage of vast virgin Douglas fir resources.

The economy after WW2 was booming, and plywood production was growing faster than ever. By 1975, the U.S. alone produced more than 1.4 billion square meters, which was double what the estimate was 20 years before. Plywood was becoming a standard building product (Engineered Wood Association n.d.). Since plywood was in such high demand the supply of large Douglas fir logs was dwindling. Researches became interested in how to glue other species together to make plywood, and in 1964, a plywood mill opened in an area other than the Pacific Northwest – the south. Georgia-Pacific opened a mill in Arkansas which was able to build plywood from the local southern pine trees. As opposed to the clear, blemish free Douglas fir panels, these sheets were full of knots, and their primary purpose was roof sheathing (Plywood Pioneers Association 1996).

Today, two thirds of North American plywood are produced in the south (Plywood Pioneers Association 1996), however, North America is no longer the dominant plywood producer they used to be. In 1967, over half of the world's plywood was produced in North America, and in 2017, they held a 7.6% share of global plywood production. China, South America and Europe have greatly increased their production since then, particularly China, which now supplies 73.1% of the world's plywood (Baldwin & Baldwin 2018).

Modern Plywood

Modern plywood can take many different forms and has many different uses from commodity to specialty. The basic component of any plywood are veneers. Veneers are thin sheets of wood that were traditionally used for covering lower value species with more attractive looking wood grains in high value furniture. Veneers can be cut from a log in several different ways, including half round, quarter slicing, and flat slicing. These are all done to obtain a different grain pattern on the final product. The most common type of slicing is rotary slicing, where the log is fixed into a lathe and a knife slices off a thin sheet of veneer. This is mostly used in commodity plywood, where the grain pattern doesn't matter, however, some decorative hardwoods where appearance is the most critical feature are quarter or flat sliced (Hoadley 2000). Once the veneers are sliced and dried, they are stacked so that each layer is perpendicular to the last, glue is applied between layers, and are clamped in a press. The resulting product, plywood, is much more stable and split resistant than solid wood. The stability comes from the perpendicular arrangement of successive plies. Since wood shrinks the most in the tangential plane, having the grain arranged perpendicular for each ply and glued together minimizes the amount the wood can shrink (Shmulski & Jones 2011). It can also be made into boards or sheets much wider than solid wood can, while maintaining uniform strength properties (Hoadley 2000). The outermost plies are called the faces and can be made from a different species of wood than the inner plies to give a more aesthetically pleasing appearance (Luostainen & Verkasalo 2000).

There are two classes that commercial plywood falls into: construction, and decorative. Decorative plywood is constructed so that the aesthetic qualities are presented on the face veneers. Usually the face veneers are a high value hardwood such as walnut or oak, but the inner plies are typically made from softwood, or even an engineered product like MDF (Hoadley 2000). Grading of decorative plywood is also based on its appearance from grade A, which has matched veneers and no defects visible, to backing grade which has knots and defects. Typical uses of decorative plywood are furniture and cabinetmaking (Hoadley 2000). Decorative panels are also classed based on adhesive resistance to moisture. Technical and Type I will resist delamination in all conditions, Type II will resist moisture but should not be exposed for long times to moisture, and Type III has low moisture resistance (Siim et al. 2012).

Construction (or “structural”) plywood is made from rotary cut veneers and is usually made from softwood species. Appearance is of little affect, and structural properties are the most important. There are grades for the appearance however, and these range from D-grade (worst) to A-grade (best). Construction plywood can have two different grades on its classification stamp indicating the grade on both sides, for example an A-C grade panel would have an A-grade veneer on one side and a C-grade veneer on the other. A special N-grade is the highest quality and is typically used for cabinetmaking or furniture (Hoadley 2000). Birch plywood in Europe is used for both decorative and structural purposes.

White Birch *(Betula papyrifera)*

A common tree species in Ontario is *(Betula papyrifera),* or white birch. It has distinctive thin white, papery bark that peels off in sheets. It is a medium sized tree, up to 25 meters in height and rarely lives past 140 years old (Uchytil 1991). It requires full sunlight, and so mostly grows as a pure stand in a disturbed stand, although it's prolific seeding and indifference to soil conditions means it can compete in gap dynamics in undisturbed forests (Frelich & Reich 1995). The wood is of medium density (average specific gravity of .55). Sapwood is pale yellow to white and heartwood is reddish brown. Growth rings are difficult to distinguish, as the pores are diffuse, giving particularly the sapwood a uniform appearance (Hoadley 2000). The sapwood is highly appreciated for its appearance but can become discoloured through the drying process. This discoloration is thought to be caused by extractives in the wood changing during drying (Fuentealba et al. 2011). This discolouration is a major source of downgrading in the industry, and the cause of substantial financial loss (Fuentealba et al. 2008).

White birch grows throughout Ontario, appearing both in the boreal forest in the north and the Great Lakes-St. Lawrence forest in south-central Ontario (Figure 1). The provincial forest inventory in 2016 estimated that there is 315 million cubic metres of white birch growing on crown land in Ontario alone (Government of Ontario 2019). Despite making up 8% of the provinces growing stock, white birch only makes up 3% of the annual harvest in Ontario, mostly being used as firewood, veneer, feedstock for pulp and specialty products (Government of Ontario 2019). It is generally regarded as an underutilized species (Belleville et. al. 2011).

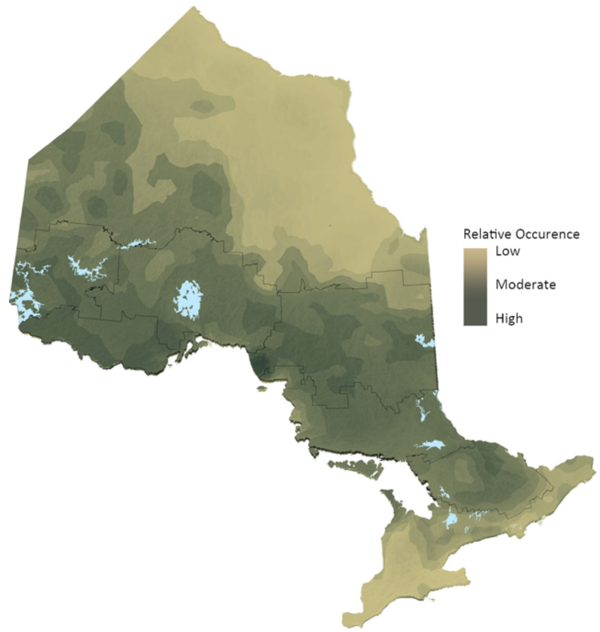

Figure 1. Relative occurrence of white birch (*Betula papyrifera*) in Ontario (Government of Ontario 2019)

Birch Plywood in Europe

Rotary cutting of birch logs for veneer started in 1894 and was used as plywood for furniture, and since 1918 has been the most important use of birch in Finland (Luostainen & Verkasalo 2000). Nowadays in Europe, particularly the Baltic region of Finland, Latvia, Lithuania, Estonia and Northwest Russia produces large amounts of birch plywood, colloquially known as “Baltic birch”. In 2005, these 5 countries produced 3.18 million cubic meters of birch plywood, which is more than three times the amount of softwood plywood they produced (Verkasalo et al. 2007). Russia is by far the leader in plywood production in this area. In 2004, Russia exported 1.4 million cubic meters of plywood, representing well over half of that year’s production, with the biggest importers of Baltic birch being USA, Great Britain, Estonia and Germany (Karvinen et al. 2006). 90% of birch logs from this area are used in veneer or plywood (Verkasalo et al. 2007).

The plywood produced in Europe is made completely out of birch veneers, no softwood or MDF core is used. This makes it a very dense, sturdy and uniform building material that is very aesthetically pleasing (Hoadley 2000).

Uses and Value-Added Activities

Russia uses Baltic birch plywood in the construction industry, particularly for concrete formwork, as they still build with mostly masonry. It is well suited for formwork, because of its ability to tolerate moisture and temperature changes, but also, it's strength and stability. There is a growing demand for Baltic birch in furniture making as more expensive furniture is becoming more popular (Terzeiva 2008). A very popular use for Baltic birch plywood is in cabinetmaking. Not only does it have excellent structural properties, it also has good aesthetic properties. The tight grained light wood is easily stainable and the thin birch veneers give it added stability to keep finishing surfaces flat (Columbia Forest Products 2018). There are many composite products on the market, but as Jonsson et al. (2008) points out, consumers prefer the look of real wood over composites.

Any material made from wood cannot withstand high temperatures and can lose structural integrity rapidly in a fire (White & Dietenberger 2010). This can lead to extensive property damage and life-threatening situations. There has been a considerable interest in improving its fire-retardant capabilities. There are several methods of inserting fire retardants into plywood panels such as mixing it with the glue, soaking the veneers before gluing, using vacuum pressure and applying a flame-retardant coating (Bryn et al. 2016). The most recommended method is raw veneer impregnation, both from an economic and effectiveness standpoint (Bryn et al. 2016). This not only makes plywood safer but can be a value-added activity for producers and reach wider markets.

Another issue that can affect birch plywood is its susceptibility to moisture, as it is a natural material. When in contact with moisture, it tends to rot, lowering its strength and eventually leading to failure. Birches in particular have very low resistance to decay (Hoadley 2000). There are, however, a number of ways to treat plywood so that it can be used in exterior applications. One such form is thermally modifying, or heat treating it to decompose hemicellulose. According to Khanasanshin et al. (2016) this is an effective means of protecting it from the elements. A much more common type of treatment is impregnating it with preservative chemicals such as copper napthaline or oxine copper (American Plywood Association 2013). With these treatments, it is approved to be used in exterior and ground contact applications.

Materials and Methods

Materials

The focus of this study is a plywood, very similar to Baltic birch, but made with North American white birch. It is manufactured by Columbia Forest Products in Hearst, Ontario using the local native birch trees. It is currently in the early stages of production. The sample from the North American birch plywood is collected from a sheet of 1-inch thick plywood, with 7 inner plies of equal thickness birch veneer and two thinner face veneers, also made of birch. The other type of plywood that the new plywood will be compared to is softwood plywood. The softwood plywood was purchased locally, and it was ¾" thick, as no 1" sheets could be found. The softwood plywood was constructed out of black spruce (*Picea mariana*) and had 6 veneer layers, with the two center plies oriented the same way.

Methods

In order to do a comparison study, the physical and mechanical properties of each different panel must be known. To measure these, testing will be done at the Lakehead University Wood Science Testing Facility in Thunder Bay, Ontario. The same testing will be done to both wood-based panels to be able to complete a comparative study. The tests that will be done can be found in Table 1. These tests will be done according to ASTM Standard Designation: D1037−12 Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials. This standard was chosen because it is specifically for obtaining properties used for comparing different construction materials. It also has provisions for using panels of different thicknesses and getting results that can be compared to each other, as no 1” softwood plywood could be found. For example, Note 10 in ASTM D1037−12 explains the need for a span-thickness ratio in order to accurately compare materials of different thickness (ASTM D1037-12). All specimens spent a minimum of two weeks in a conditioning chamber to bring them to the same moisture content and temperature.

Three tests were completed to evaluate different properties of the plywood. These tests and their descriptions can be found in Table 1.

Table 1. This table shows the properties to be measured and their section in ASTM D1037−12.

PLYWOOD PROPERTY	DESCRIPTION OF TEST
STATIC BENDING	Section 5 of ASTM D1037−12
COMPRESSION	Section 12 of ASTM D1037−12, using test method A (Section 12.2.2)
HARDNESS MODULUS	Section 18 ASTM D1037−12

Results

Compression parallel to the grain

Max stress in compression parallel to the grain was measured in MPa. Max load was measured in N. Table 2 shows the values for each type of plywood.

Table 2. Values from the compression parallel to the grain test.

Max Load (N)		
	Bwply	Sftply
Average	16367	13260
Maximum	17680	15090
Minimum	13280	11330
Max Stress (MPa)		
	Bwply	Sftply
Average	25.7	27.1
Maximum	27.8	30.4
Minimum	20.7	22.7
Standard Deviation	1.453889	2.059184

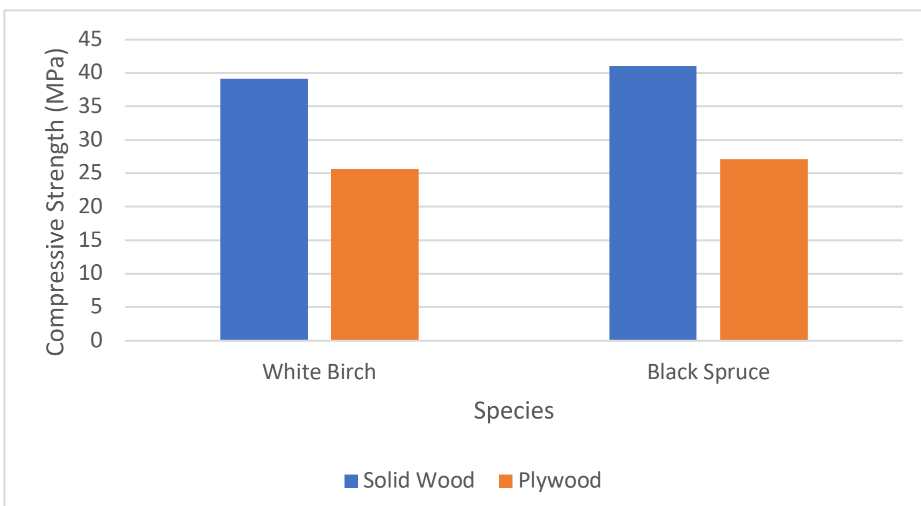

Figure 2. Comparison of white birch and black spruce plywood and solid wood in compressive strength parallel to the grain.

The average max load (N) required to reach the failing point of the birch plywood was higher than the softwood plywood by 3107 N. Both the maximum and minimum values were also higher for the birch plywood by 2590 N and 1950 N, respectively. The average max stress (MPa), minimum and maximum max stress for the softwood plywood, however, was higher. The average max stress of the softwood plywood was higher by 1.4 MPa. The maximum and minimum were also higher for the softwood plywood by 2.6 MPa and 2.0 MPa, respectively.

Hardness

The values obtained from the hardness test are found in Table 3. The max stress of the hardness test was measured in Newton's and the max load was measured in kilograms. The average, minimum and maximum values for max load are all higher for the birch plywood than the softwood plywood by 185, 201 and 170 kg, respectively. The max stress for the birch plywood was 4041 N, which was higher than the softwood plywood at 2221.5 N by 1820.2 N. The maximum and minimum max stress of the birch plywood were also higher by 1980 and 1671 N, respectively. The standard deviation of the birch plywood was 241.5, and the standard deviation of the softwood plywood was 175.7.

Table 3. Values from the Janka hardness test.

Max Load (kg)		
	Bwply	Sftply
Average	1412	1226.583
Maximum	1463	1262
Minimum	1357	1187
Max Stress (N)		
	Bwply	Sftply
Average	4041.667	2221.458
Maximum	4550	2570
Minimum	3510	1834
Standard Deviation	241.5172	175.669

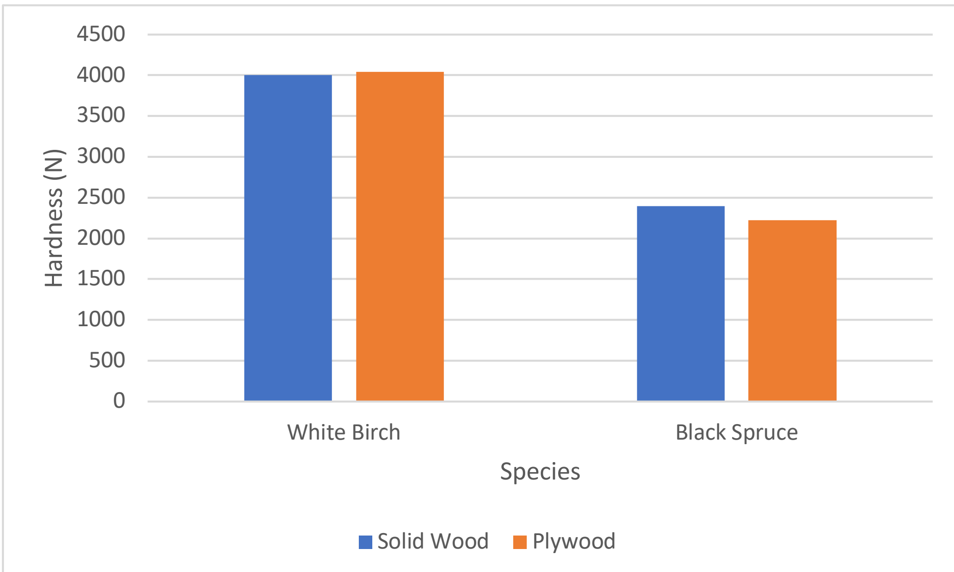

Figure 3. A comparison of hardness between plywood and solid wood for black spruce and white birch.

Modulus of Elasticity (MOE)

The modulus of elasticity was measured in MPa, and testing values can be found in Table 4.

Table 4. Values from the static bending tests.

MOE (MPa)		
	Bwply	Sftply
Average	5786.146	7056.377
Minimum	6722.989	8009.213
Maximum	4551.645	5643.119
Standard Deviation	490.1399	680.3581

All values were higher for softwood plywood than for birch plywood. The average for softwood plywood was higher than the average for birch plywood by 1270 MPa. The minimum softwood plywood MOE was 1091 MPa higher than that of birch plywood, and the maximum softwood plywood was 1286 MPa higher than that of birch plywood. The standard deviation was 190 units higher for softwood plywood than for birch plywood.

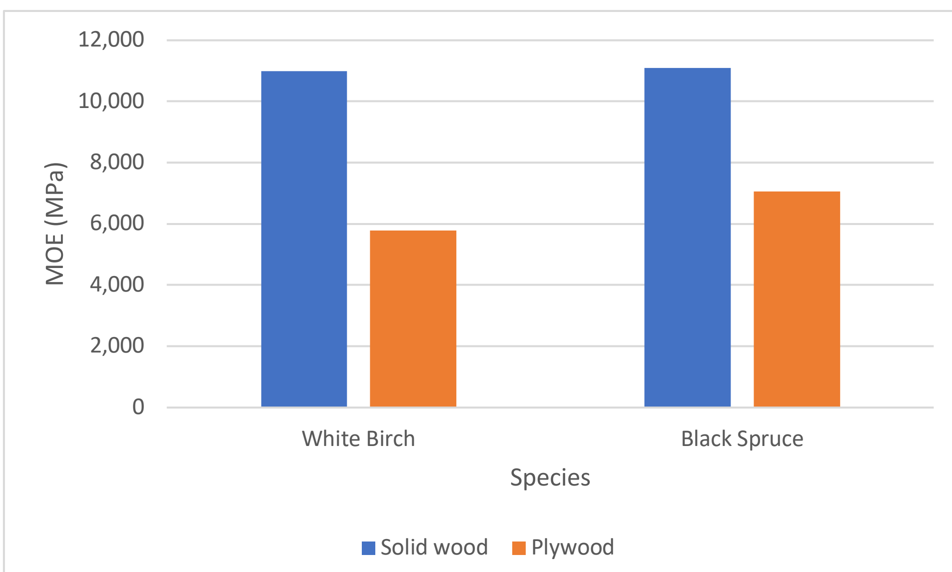

Figure 4. A comparison of MOE values for black spruce and white birch in both solid wood and plywood.

Discussion

Compression Test

Overall, the softwood plywood was stronger in this test than the birch plywood. According to Kretschmann (2010) solid white birch at 12% moisture content has compressive strength parallel to the grain of 39.2 Mpa, which is 13.5 Mpa higher than the average max stress value obtained from the test. Black spruce has compressive strength parallel to the grain of 41.1 Mpa, which is 18.4 Mpa higher than the plywood from which it is made. Since the compressive strength of solid black spruce is higher than that of white birch, the values obtained from the test are not surprising. Since the difference in compressive strength between solid birch and birch plywood is smaller than its black spruce counterpart, this study suggests that the construction and arrangement of the birch plywood retains more of the solid wood's strength in this plane than does the softwood plywood, as can be seen in Figure 2.

The fact that both plywood values are lower than their corresponding solid wood values could be because all the fibres in solid wood are parallel to the force acting on them. In plywood, every other ply is perpendicular to the grain, an orientation in which wood generally is not as strong (Hoadley 2000).

The standard deviation in compressive strength parallel to the grain for the birch plywood panels was also lower, which indicates that these panels have a more predictable behaviour.

The compressive strength parallel to the grain of the white birch plywood is 25.7 Mpa, which is similar to that of the birch plywood produced in Europe, which has a compressive strength of 26.9 (Finnish Forest Industries Federation 2002). This suggests that anything that Baltic birch plywood is being used for due to its compressive strength could be replaced by North American birch plywood.

Hardness Test

The hardness of the birch plywood was 4041.7 N, which is approximately double that of the softwood plywood, with 2221.5 N. According to Kretschmann (2010), solid white birch at 12% moisture content has a hardness of 4,000 N and solid black spruce has a hardness of 2,400 N. The white birch plywood is very similar to solid birch wood in hardness, but the spruce plywood has a lower hardness than solid wood. The white birch doesn't lose any hardness when it is converted to plywood, whereas the black spruce loses approximately 180 N of hardness. This can be seen in Figure 3, where there is a drop, in hardness from solid to plywood for black spruce, but the white birch stays relatively the same.

The standard deviation of the birch plywood was higher than the softwood plywood, which means in terms of hardness, the softwood plywood is more predictable than the birch plywood.

Modulus of Elasticity Test

The modulus of elasticity is the maximum flexure load a material can withstand and still return to its original position. It is an important value because this is what a materials useful working load is based on. In these tests, the softwood plywood had a higher MOE than the birch plywood by 1270 MPa. White birch as solid wood has an MOE of 11,000 MPa and black spruce as solid wood has an MOE of 11,100, which is only a difference of 100 MPa. The comparison of these types of plywood to their solid wood counterparts can be seen in Figure 4. There is less of a difference between black spruce solid wood and plywood than there is with white birch.

Solid black spruce and white birch have approximately the same MOE, but when made into plywood, black spruce retains more of the solid wood strength than does the white birch. This could potentially be due to the construction of the panels, such as veneer thickness and gluing pressure (Palka 1961), or the characteristics of the glue line (Okume 1976). The MOE of the white birch panel is lower than that of the black spruce panel, but replacing spruce plywood with birch plywood could be possible provided it meets the strength requirements described in CSA 0151 – Canadian Softwood Plywood.

Birches and spruces are both in the slightly resistant or non-resistant category in terms of ability to resist decay (Hoadley 2000), however spruce plywood can be used as exterior grade plywood if the correct adhesives are used. This suggests birch could be treated the same way and used as a replacement in terms of weather protection.

Baltic birch plywood has an MOE of 7783 MPa, which is higher than both the birch and softwood plywood tested in this study (Finnish Forest Industries Federation

2002). Baltic birch plywood has approximately 2000 MPa higher MOE than does North American birch plywood, and roughly 700 MPa higher than softwood plywood. A direct replacement of Baltic birch with North American birch might not be possible for structural applications requiring a high MOE, although this is subject to respective CSA Standards. Baltic birch is normally used in cabinetry (LeGros 2019), which has no strength standards, so North American birch would be a suitable replacement.

A note about the aesthetics is important to remember. After all, Baltic birch plywood is used in North America for applications where aesthetic properties are the most important (LeGros 2019), and decorative applications could possibly be the only large-scale use of this product in the future. Although it was not measured quantitatively, the panels received from Columbia Forest Products were very uniform in appearance both on the face and on the edges. The light white colour of the face veneers are attractive, and there were very little defects in them. This means they could be suitable for use in cabinetry and as decorative panels based on their aesthetic qualities.

Conclusion

Plywood made from softwoods is a very popular building material in the North American construction market. In Europe, manufacturers have been successfully producing plywood from their native silver birch. There is plenty of white birch standing volume in Ontario, and much of it goes underutilized, or goes to low value products like firewood. This underutilized wood could be used to make plywood, provided the finished product has acceptable mechanical and physical properties. Columbia Forest Products' mill in Hearst, Ontario has recently begun production of plywood made from native white birch. When tested, the North American birch plywood was much higher in hardness than softwood plywood, suggesting it could be used in applications such as industrial floors. Birch plywood is lower in compressive strength than softwood plywood, but compared to Baltic birch plywood, it has a similar compressive strength, suggesting it can replace Baltic birch in applications it is being used in now, such as cabinetry, and furniture.

For structural applications such as concrete formwork and roof sheathing, the MOE of birch plywood is the most important factor. If it has acceptable strength properties, it could be used in these applications. Birch plywood does not appear to have as high of an MOE value as softwood plywood, and therefore might not be a suitable direct replacement, although verification of this requires consultation of CSA 0151. In some of these applications, the plywood is exposed to exterior conditions, and can degrade over time due to rot and delamination of veneers. Further testing of birch plywood in exterior conditions is required to judge its suitability for exterior use.

It is important to note that the birch plywood used in this study is in the early stages of production. The mill does not have any published mechanical properties as of the writing of this thesis (Bowes pers. Comm., March 18, 2020), which means that they could still be working on improving the product to make it more widely usable.

References

American Plywood Association. (2013). *Preservative Treated Plywood.* Retrieved from American Plywood Association: https://www.apawood.org/publication-search?q=treated&tid=1

ASTM D1037-12, Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials, ASTM International, West Conshohocken, PA, 2012, www.astm.org

Baldwin, R. F., & Baldwin, R. W. (2018). *Global plywood industry update*. Retrieved from Wood Based Panels International: http://www.wbpionline.com/features/global-plywood-industry-update-6908934/##targetText=The%20FAO%20(UN%20Food%20and,trend%20in%20China%20is%20unprecedented.

Bryn, O., Bektha, P., Sedliacik, Forosz, V., & Galysh, V. (2016). The effect of diffusive impregnation of birch veneers with fire retardent on plywood properties. *BioResources, 11*(4), 9112-9125.

CSA 0151-09 Canadian Softwood Plywood. Canadian Standards Association. 2014

Columbia Forest Products. (2018, April 10). *Choosing the Best Birch Plywood for Cabinets*. Retrieved from Columbia Forest Products: https://www.columbiaforestproducts.com/2018/04/10/choosing-best-birch-plywood-cabinets/

Engineered Wood Association. (2010). *PS 1-09 Structural Plywood*. Retrieved from APA- The Engineered Wood Association: https://apawood-europe.org/wp-content/uploads/2013/07/PS-1-09-+APA-trademarks.pdf

Engineered Wood Association. (n.d.). *History of APA, Plywood, and Engineered Wood*. Retrieved from APA: https://www.apawood.org/apas-history

Finnish Forest Industries Federation. (2002). *Handbook of Finnish Plywood.* Lahti, Finland: Kirjapaino Markprint Oy. 67p.

Frelich, L., & Reich, P. (1995). Spatial patterns and succession in a Minnesota southern boreal forest. *Ecological Monographs, 65*(3), 325-346.

Fuentealba, D., Diouf, P., Fortin, Y., & Stevanovic, T. (2008). Characterisation of Birch (Betula papyrifera Marsh.) wood discoloration during drying in *Proceedings of the 51st International Convention of Society of Wood Science and Technology* (pp. 1-7). Concepcion: Department of Wood Science and Forestry, Laval University.

Government of Ontario. (2019, October 16). *White Birch – Betula papyrifera*. Retrieved from Ontario.ca: https://www.ontario.ca/document/forest-resources-ontario-2016/white-birch-betula-papyrifera

Hoadley, R. (2000). *Understanding Wood A Craftsman's Guide to Wood Technology.* The Taunton Press*,* Newton, CT. 280p.

Jonsson, O., Lindberg, S., Roos, A. H., & Lindstrom, M. (2008). Consumer Perceptions and Preferences on Solid Wood, Wood-Based Panels, and Composites: A Repertory Grid Study. *Wood Fibre and Science, 40*(4), 663-678.

Karniven, S., Valkky, E., Torniainen, T., & Gerasimov, Y. (2006). *Northwest Russian Forestry in a Nutshell.* Helsinki: Finnish Forest Research Institute.

Khasanshin, R. R., Safin, R. R., & Razumov, E. Y. (2016). High temperature treatment of birch plywood in the sparse environment for the creation of a waterproof construction veneer. *Procedia Engineering, 150*, 1541 – 1546.

Kretschmann, D. (2010) Mechanical Properties of Wood, 5-1 - 5-55. in *The Wood Handbook: Wood as an Engineering Material. United States Department of Agriculture, Forest Products Laboratory, Madison, WI. 508p.*

LeGros, S. (2019). *All About Baltic Birch Plywood*. Retrieved from Forest Plywood: https://forestplywood.com/blog/all-about-baltic-birch/

Luostainen, K., & Verkasalo, E. (2000). Birch as sawn timber and in mechanical further processing in finland. A literature study. *Silva Fennica Monographs 1*, 1-40.

Morris, T. (2017, July 14). *Plywood: The underrated material that shaped our modern world*. Retrieved from CNN News: https://www.cnn.com/style/article/plywood-material-of-the-modern-world-victoria-albert-museum/index.html

National Forest Inventory. (2016). *Statistical Reports*. Retrieved from Canada's National Forest Inventory: https://nfi.nfis.org/en/statisticalreports

Okuma, M. (1976). Plywood Properties Influenced by the Glue Line. *Wood Science and Technology, 10*, 57-68.

Palka, L. (1961) Factors influencing the strength properties of Douglas fir plywood normal to the glue line. Master's Dissertation, Department of Forestry, Univ. of British Columbia, Vancouver, BC. 118p.

Plywood Pioneer's Association. (1967). *Portland Manufacturing Company No. 1*. Tacoma, Washington: Plywood Pioneer's Association.

Plywood Pioneers Association. (1996). *G-P Fordyce No. 20.* Tacoma, WA: Plywood Pioneers Association. Retrieved from https://www.apawood.org/data/Sites/1/documents/monographs/20-g-p-fordyce.pdf

Shmulski, R., & Jones, P. D. (2011). Structural Composites 328-339 *in* Shmulski, R., & Jones, P. D. *Forest Products and Wood Science.* John Wiley & Sons*,* Chichester UK. 447

Siim, K., Kask, R., & Lille, H. &. (2012). Study of physical and mechanical properties of birch plywood depending on moisture content. *in 8th International DAAAM Baltic Conference"INDUSTRIAL ENGINEERING"* (pp. 735-740). Tallinn, Estonia: DAAAM Baltic.

Terzeiva, E. (2008). *The Russian birch plywood industry – Production, market and future prospects. Masters Dissertation.* Uppsala: Swedish University of Agricultural Sciences, Department of Forest Products.

Uchytil, R. J. (1991). *Fire effects information system : Betula papyrifera*. Retrieved from United States Department of Agriculture: https://www.fs.fed.us/database/feis/plants/tree/betpap/all.html

Verkasalo, E., Toppinen, A., Arponen, J., & Henrik, H. (2007). Perspectives of wood resources, industry competitiveness and wood products markets for birch industries in the Baltic Sea area. *in Proceedings of the ISCHP '07* (pp. 29-35). Quebec City: International Scientific Conference on Hardwood Processing.

White, R. and Dietenberger, M. (2010) Fire Safety of Wood Construction p. 18-1 - 18-22 *in* United States Department of Agriculture. Wood Handbook: Wood as an Engineering Material. United States Department of Agriculture, Forest Products Laboratory, Madison, WI. 508p.

Wood Database. (n.d.). *Silver Birch*. Retrieved from Wood Database: https://www.wood-database.com/silver-birch/