Feasibility of Producing Non-structural Wood Products Using Aspen Lumber

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EXECUTIVE SUMMARY

Trembling aspen (*Populus tremuloides*) is an abundant resource in Alberta, which is considered as an underutilized species. This project aimed at assessing the feasibility of using trembling aspen to produce non-structural wood products, including flooring, moulding, exterior siding, and preservative-treated lumber. This report outlines the research procedures and major findings.

Aspen lumber was sampled from a sawmill in Alberta. The following properties of aspen wood were evaluated at the University of New Brunswick's Wood Science and Technology Centre (WSTC):
(1) physical properties, including dimensional stability, density/specific gravity (SG), moisture content (MC), surface roughness, wettability, and coating penetration depth;
(2) mechanical properties, such as surface hardness, screw withdrawal resistance, and coating adhesion strength; and
(3) machining properties, including planing and sanding.

The properties of aspen products fabricated in this project were also tested for selected applications, including surface hardness of flooring, screw withdrawal resistance of moulding, weathering and screw withdrawal performance of exterior siding, and preservative penetration and retention of treated lumber. Furthermore, the aspen lumber yield for making a given product was estimated.

It was found that:
(1) Aspen wood demonstrated average shrinkage of 6.1 %, 5.2 %, and 0.1 % in tangential, radial, and longitudinal directions, respectively.
(2) Sanded aspen wood exhibited an adhesion strength of 3.80 MPa, which is 7.6 % higher than that of planed surfaces.
(3) Aspen wood exhibited a Brinell hardness of 22.51 MPa and screw withdrawal resistance of 20.90 MPa in the radial direction, which were 30.0 % and 5.6 % higher than those in the tangential direction.
(4) Aspen flooring had a Brinell hardness of 13.47 MPa, which is 59.5 % lower than silver maple flooring.
(5) Aspen moulding had an average screw withdrawal resistance of 23.42 MPa, 13.0 % lower than yellow poplar and 17.6 % higher than eastern white pine.
(6) The "freeze-soak-thaw" accelerated weathering test caused dimensional changes, with unfinished aspen increasing by 70.8 %, leading to the formation of surface checks and end splits.
(7) Surface finishing preserved colour and durability in aspen, with finished specimens showing only a 1.6 % colour change, while unfinished specimens experienced a 19.0 % shift from yellow to blue, transitioning from light brown to uniform gray.
(8) Aspen and S-P-F siding exhibited similar colour change trends during accelerated weathering treatment, but aspen demonstrated greater colour stability, suggesting its potential for further research as an exterior siding material.
(9) Aspen lumber was more difficult to treat with preservatives than S-P-F.
(10) The yields for aspen flooring, moulding, and siding were 35.2 %, 25.4 %, and 49.2 %, respectively with the lumber stock being No. 2 grade or better.

Further evaluation of aspen lumber is recommended:
(1) An optimal surface dressing approach should be developed when using aspen to produce siding.
(2) Extended weathering tests are recommended for more reliable long-term results including both natural and accelerated

treatment.
(3) A thorough yield study should be performed in each production line when using aspen to produce a given non-structural product to fully understand the economic benefit.

Keywords: Trembling aspen, non-structural wood products, moisture content, specific gravity, planing, sanding, flooring, moulding, exterior siding, preservative-treated lumber.

Acknowledgements

This project was financially supported by WoodWorks Alberta under the Alberta Value-Added Wood Products Program. Funding was provided to the Advanced Research in Timber Systems Group at the University of Alberta and the Wood Science and Technology Centre at the University of New Brunswick. We gratefully acknowledge the material and manufacturing support provided by Alberta Forest Products Association (AFPA), Zavisha Sawmills Ltd. (Alberta), La Crete Sawmills Ltd. (Alberta), Marwood Ltd. (New Brunswick), Cape Cod Siding Ltd. (Nova Scotia), Colonial Manufacturing Ltd. (New Brunswick), and Norwood Windows Ltd. (New Brunswick). We would also like to express our sincere thanks to Mr. Gregory McCarthy, Chief Technologist at the University of New Brunswick, for his invaluable support throughout the project.

TABLE OF CONTENTS

1 BACKGROUND

In Canada, softwood and hardwood forests cover about 66% and 12% of forest land respectively, with the remaining 22% being mixed forests. The dominant hardwood species are trembling aspen (*Populus tremuloides*), sugar maple (*Acer saccharum*), and white birch (*Betula papyrifera*) (Natural Resources Canada 2022). Aspen/poplar is a significant deciduous resource, particularly in Alberta, where over 800 million m^3 of standing timber is primarily composed of aspen, accounting for approximately 80.0 % of this group (Karaim et al. 1989). Therefore, aspen is used here to represent the entire category. Aspen possesses lightweight characteristics and favorable processing properties. Currently, the Canadian wood industry primarily uses aspen for producing oriented strand board (OSB), bleached kraft pulp, pallets, and low-grade lumber (Karaim et al. 1989). However, there is growing demand in North America for non-structural wood products such as flooring, moulding, and siding, which require new material sources. Unlike structural wood products, non-structural products prioritize physical properties such as surface quality and coating performance over mechanical properties.

This project aimed to evaluate the feasibility of using aspen for non-structural wood products, such as flooring, moulding, cabinetry, exterior siding, and treated lumber, while analyzing production yields, and building a comprehensive database on the physical, mechanical, and machining properties of aspen wood. To achieve these objectives, the scope of the research was as follows:

1. Conducting a series of tests on aspen wood and lumber, evaluating its physical properties (including specific gravity (SG), dimensional stability, and moisture content (MC)), mechanical properties (including hardness and screw withdrawal resistance), and machining properties (including planing, sanding, roughness, wettability, coating, and paint performance).
2. Using aspen lumber to manufacture non-structural products for interior use, including flooring and moulding, and analyzing the potential yield of a given product.
3. Utilizing aspen lumber to manufacture non-structural products for exterior use, including finished siding and preservative-treated lumber, and assessing the potential yield of a given product.

This project comprised two (2) phases of research, as illustrated in Figure 1.

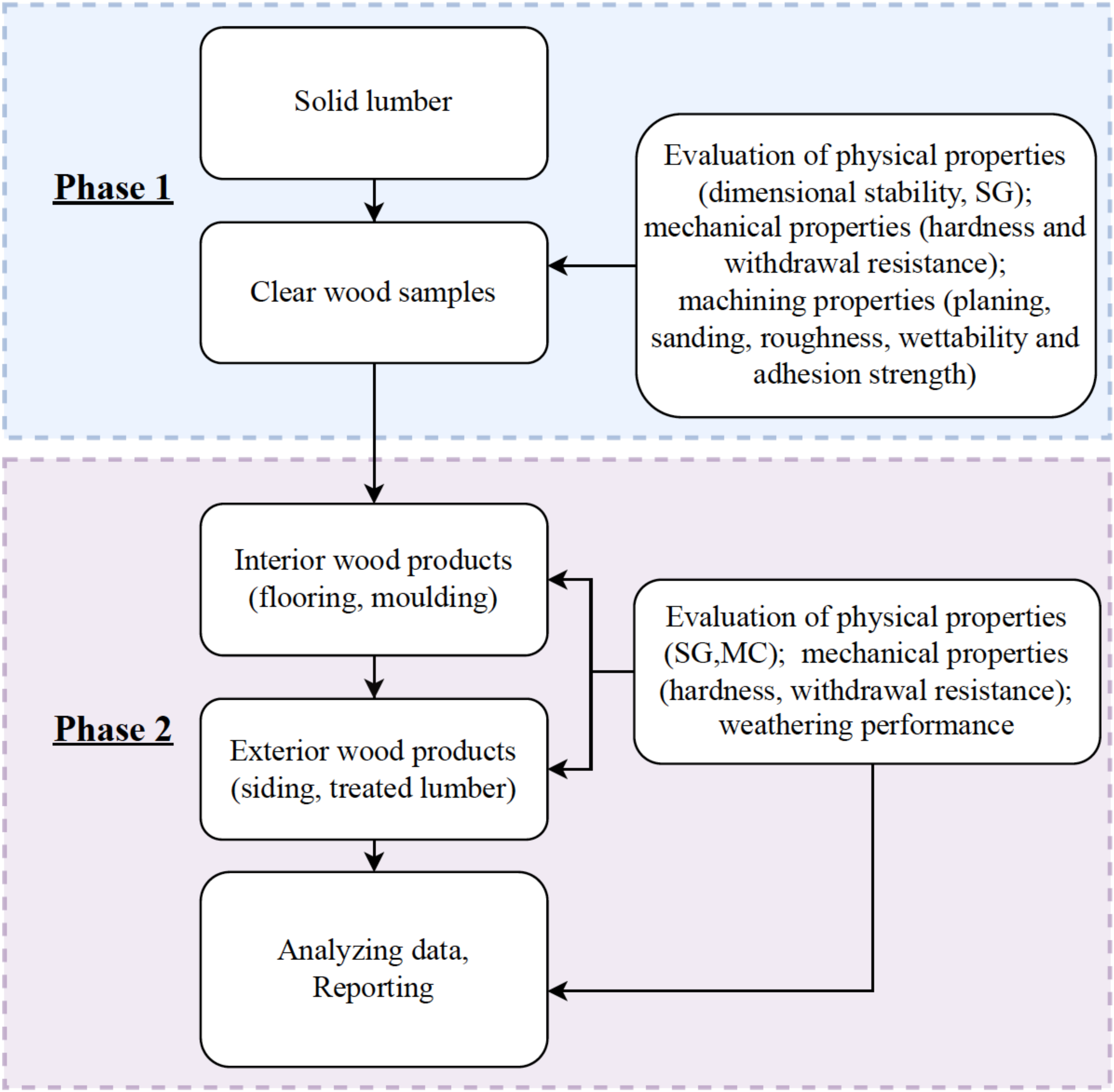


Figure 1 - Flowchart of Research Program.

2 Trembling Aspen Wood Test Results

2.1. Materials

The 2 × 4 (38 mm × 89 mm) trembling aspen lumber used in this study was sourced from a sawmill in Hines Creek, Alberta, as shown in Figure 2a. Detailed information on the logs from which this lumber was produced, such as diameter, taper, length, and any decay, was recorded. The lumber recovery and grade yield were analyzed after each stage of the process, including sampling and drying. The lumber was graded by a grading inspector from the Alberta Forest Products Association according to the Canadian Lumber Standards Grading Rules (NLGA 2019). All lumber specimens were wrapped and shipped to the Wood Science and Technology Centre at the University of New Brunswick, Fredericton, for further conditioning (see Figure 2b), testing, and characterization. In Phase 1, clear wood specimens were selected and cut from No. 2 and better lumber. These clear wood specimens were then tested for physical properties, mechanical properties, and machining properties.

Figure 2 - (a) Trembling aspen lumber sampling in Hines Creek, AB; (b) Lumber conditioning in Fredericton, NB.

2.2. Testing

2.2.1. Testing Program of Phase 1

The flowchart in Figure 3 illustrates the testing program for clear aspen specimens in Phase 1 of the study.

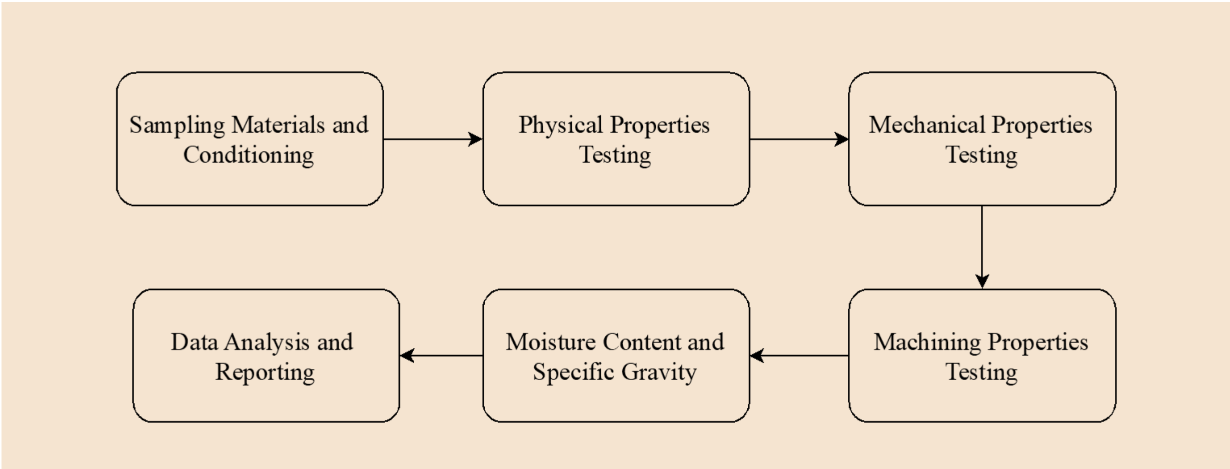


Figure 3 - Property testing program in Phase 1.

2.2.2. Physical Properties

2.2.2.1. Dimensional Stability

Dimensional stability refers to the extent to which wood maintains its shape and size when exposed to changes in MC. In this study, stability of aspen wood was evaluated by measuring shrinkage in the radial, tangential, and longitudinal directions, as well as overall volume, as the wood dried from a MC above the fibre saturation point (FSP) to an oven-dry state. The tests followed ISO 13061“Physical and mechanical properties of wood, Part 13: Determination of radial and tangential shrinkage” (ISO 2016) and ASTM D143 “Standard test methods for small clear specimens of timber: (ASTM 2022) standards. Thirty-two (32) clear wood blocks, each 1 in. × 1 in. × 1 in. (L × R × T) in dimensions, were carefully selected to avoid reaction wood and defects, ensuring that each block contained at least one complete growth ring (Figure 4). Specimens were fully saturated using a vacuum-pressure pump, and their initial dimensions and weight were recorded. They were then placed in an oven at 50 ± 5 °C, with measurements taken every 2 hours initially, then every 24 hours until dimensional changes between consecutive measurements were less than 0.02 mm. The oven temperature was then increased to 103 ± 2 °C to achieve oven-dry conditions.

The recorded data provided shrinkage values in the radial, tangential, and longitudinal directions, as well as volumetric shrinkage, alongside the shrinkage curve as a function of MC. Additionally, the density and SG of the aspen specimens were accurately determined

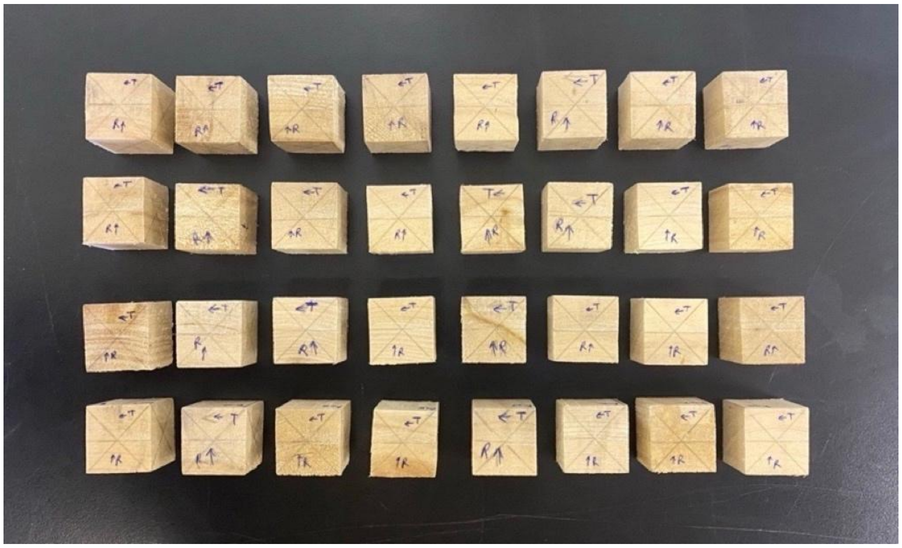


Figure 4 - Test specimens and end-grain images.

2.2.2.2. Density and Specific Gravity (SG)

In the dimensional stability test, the dimensions and weight of the specimens were recorded, and after achieving an oven-dry state, density and SG were calculated.

2.2.3.Mechanical Properties

2.2.3.1. Surface Hardness

The Brinell hardness (HB) test measures the resistance of wood to indentation, providing an indication of surface hardness. In this study, the test was used to assess the hardness of aspen and black spruce (*Picea mariana*) in both R and T directions. The test was conducted in accordance with the EN 1534 “Determination of resistance to indentation” (EN 2011). Clear wood specimens of aspen and black spruce, each measuring 1 ft. in length, 2 in. in width and 2 in. in thickness, were selected for testing. An Instron universal testing machine (Model: 3367) was used for the tests, as shown in Figure 5, where a steel ball with a diameter of 10 mm (0.44 in.) was applied, reaching a load of 1 kN at 15th second. The load was maintained for 25 seconds, and then the steel ball was entirely released (Figure 6). The maximum indentation depth (*h*) was recorded, and the Brinell hardness was then calculated according to Eq. 1:

$$HB = \frac{F}{\pi D h} \#(1)$$

where, *HB* is the Brinell hardness (MPa), *F* is the applied force (N), *D* is the diameter of indenter (mm), and h is depth of indentation (mm).

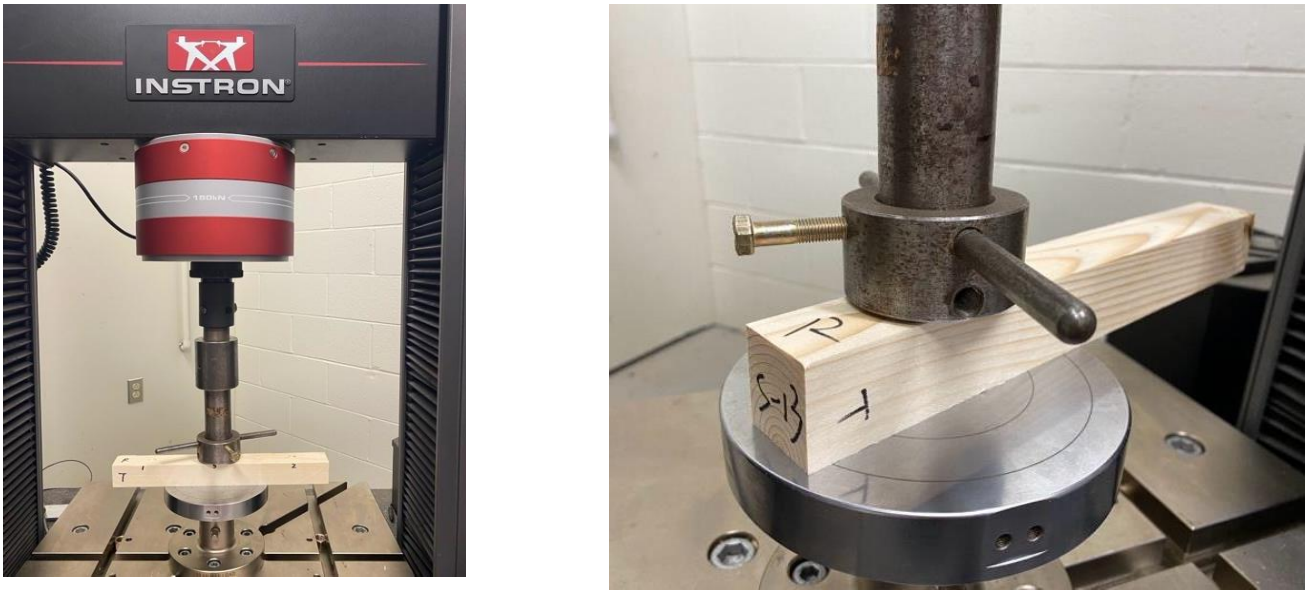


Figure 5 - Setup for testing the surface hardness of aspen wood.

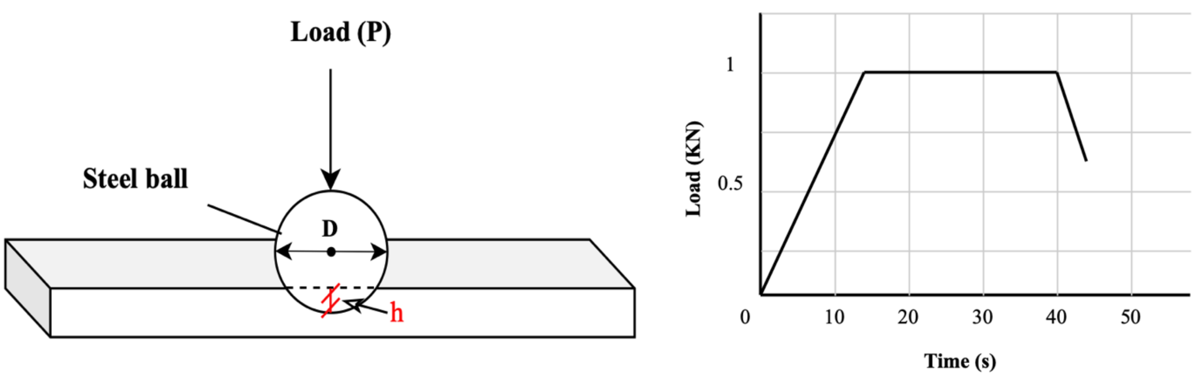


Figure 6 - Brinell hardness geometric diagram sketch (left) and load mode diagram (right).

2.2.3.2. Screw Withdrawal Resistance

The withdrawal resistance of screws refers to the force required to pull the screw out of the wood, indicating the wood's ability to hold fasteners securely. It was determined according to ASTM D1761 "Mechanical Fasteners in Wood and Wood-Based Materials" (ASTM 2020). Clear wood specimens of aspen, measuring 450 mm × 33 mm × 33 mm (1.5 ft. × 1.3 in. × 1.3 in.) (length × width × thickness) in dimensions, were selected for testing. Prior to driving the screws into specimens, the materials were conditioned at a relative humidity (RH) of 65 ± 3% and a temperature of 20 ± 2 °C. Paulin #5 × 1 screws with a major diameter of 3.32 mm (0.13 in.), were used and inserted in the specimen with pre-drilling by a drill press (Model: General 340). The pre-drilled hole was made at 70 % of the screw diameter, resulting in a 2.32 mm (0.09 in.) hole. The screws were driven in three directions relative to the wood grain: R, T, and L, with 16.0 mm penetration depth for all specimens (Figure 8). Withdrawal tests were carried out immediately after specimen fabrication. The specimens were tested by means of an Instron universal test machine (Model: 3367), with a constant pulling speed of 3 mm/min applied until the screws were completely separated from the wood specimen. The withdrawal parameter of the screw was calculated according to the following expression (Eq. 2.):

$$f = \frac{F_{max}}{d \times l_p} \#(2)$$

where f is the withdrawal resistance of the screw (MPa), F_{max} is the maximum withdrawal load (N), d is the diameter of the screw (mm), and l_p is the depth of the penetration of the threaded part of the screw including the tip (mm).

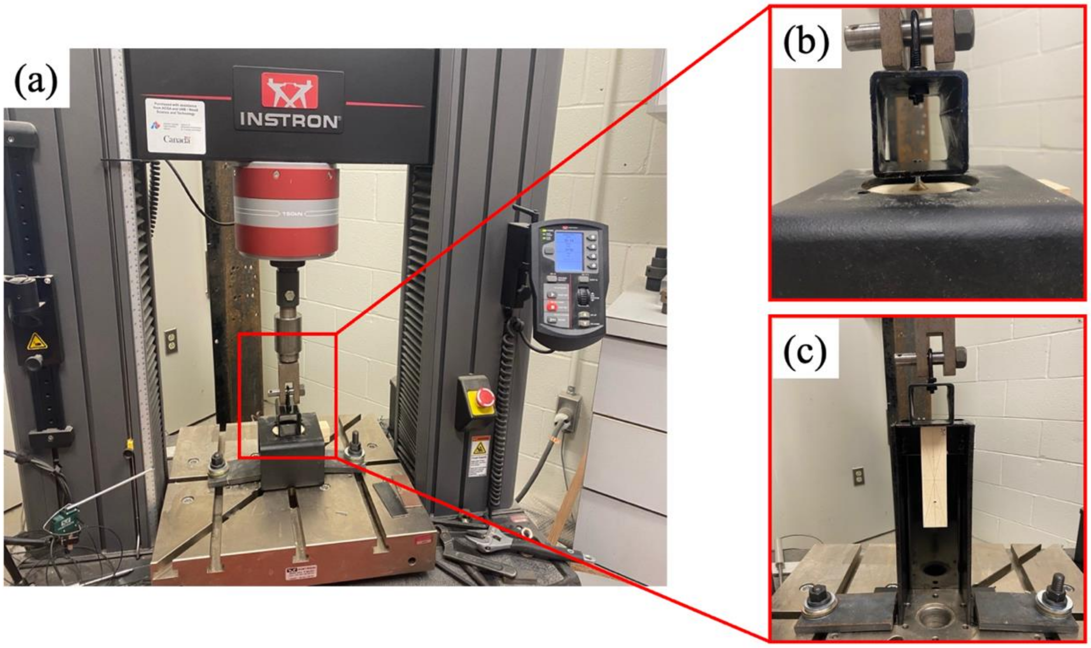
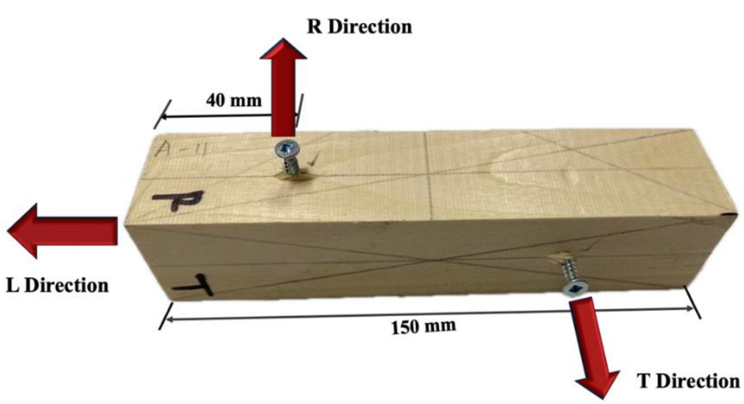


Figure 7 – Setup for testing screw withdrawal resistance of aspen wood specimens (a) in R and T directions (b), and in L direction (c).



a.

b.

Figure 8 – Geometry for screw withdrawal test in three directions.

2.2.3.3. Moisture Content (MC) and Specific Gravity (SG)

After conducting screw withdrawal and surface hardness tests, a 1-inch-thick wood block was cut from each specimen for MC and oven-dry SG determination, in accordance with ASTM D4442 “Standard test methods for direct MC measurement of wood and wood-based materials” (ASTM 2020).

2.2.4. *Machining Properties*

2.2.4.1. Machining Treatments and Surface Microscopic Evaluation

Machining Treatments

This study selected clear wood specimens, each 1 ft. in length, from four species: trembling aspen, silver maple (*Acer saccharinum*), American yellow poplar (*Liriodendron tulipifera*), and eastern white pine (*Pinus strobus*). The latter three species are commonly used in the manufacture of appearance wood products, and they were also used as reference species for comparison in this study. These specimens underwent machining processes, including planing and sanding. Subsequent tests were conducted on the planed and sanded specimens, including surface roughness measurements, contact angle assessments, and pull-off adhesion tests on the surface coatings.

All specimens were conditioned in an environmental chamber with a temperature of 20 ± 2 °C and a RH of 65 ± 3% until they reached EMC. The planing process utilized a KC 520C Straight-blade Cutterhead Planer (Figure 9a), with a feed speed adjusted between 16 and 20 feet per minute (FPM). The planer’s cutterhead, equipped with three high-speed steel (HSS) blades set at a 45-degree knife angle. The cutting depth per pass was controlled between 1.5 mm to 3 mm (1/16” and 1/8”), ensuring optimal surface quality and minimizing tear-out in the wood specimens. The specimens were sanded using a KING KC-26DS drum sander at a feed speed of 7 m/min (Figure 9b). The sanding process involved the sequential use of 80-grit and 120-grit sandpaper to achieve the desired surface finish.

a. b.

Figure 9 – Surface dressing machines: a. Planer and b. Sander.

Machining Surface Microscopic Evaluation

Machined surfaces were examined using a field-emission scanning electron microscope (JSM-6360LV, JEOL) at 15 kV. Two specimens from each surfacing method were selected, and 8 mm³ cubes were prepared to observe the tangential surfaces. The cubes were mounted and coated with carbon on the sides and a layer of gold on the surface for enhanced observation. The primary parameters assessed were fibrillation levels and open lumens.

2.2.4.2. Surface Roughness

Wood surface roughness is commonly regarded as a key quality indicator of machining processes. It is characterized by specific roughness parameters that describe the surface's texture and deviations. To measure surface roughness, a MAHR stylus unit (Model: M400) was used, featuring a 2 μm diamond stylus with a 12.5 mm tracing length. The measurement scheme is shown in Fig. 11, with specimens sourced from the same boards used in previous machining processes. The test was conducted on the specimen surfaces, with the stylus tip measuring in two directions: along the machining process (along to the wood grain) and across the wood grain.

The measurements provided a surface profile, Abbott curve, and standard roughness parameters, according to DIN 4768 "Determination of values of surface roughness parameters R_a, R_{max}, R_z using electrical contact (stylus) instruments" (DIN 1990). The primary roughness parameters assessed were R_a (arithmetic mean deviation), R_z (ten-point height of the profile), and R_{max}, (maximum two-point height). These parameters provide a quantitative evaluation of the surface texture, offering insights into the quality of the machining process. The arithmetic average height parameter (R_a), also known as the centre line average (CLA), is the most universally used roughness parameter for general quality control (Gadelmawla, et al. 2002). Therefore, the subsequent analyses focus on R_a results. Eq. 3 provides the mathematical definition of R_a.

$$R_a = \frac{1}{l}\int_0^l |y(x)|dx \#(3)$$

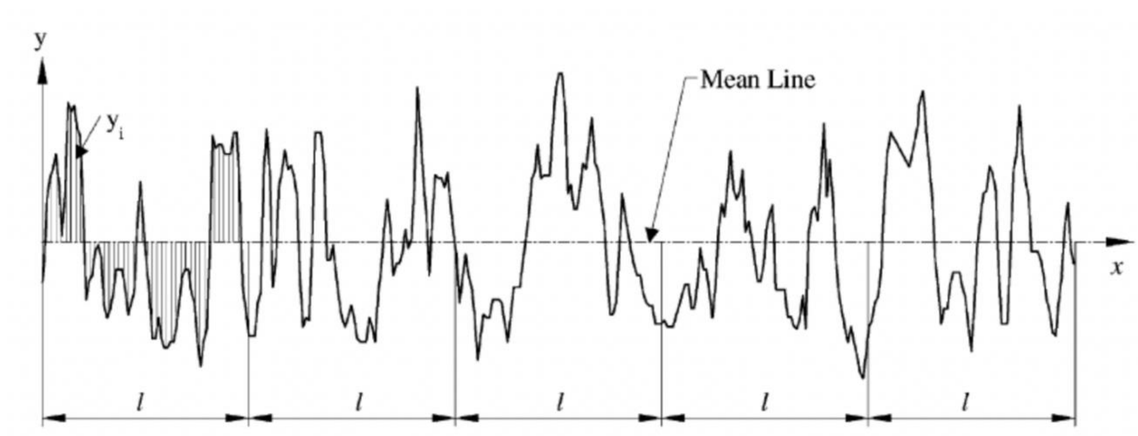


Figure 10 – Definition of the arithmetic average height (Ra) (Gadelmawla et al. 2002).

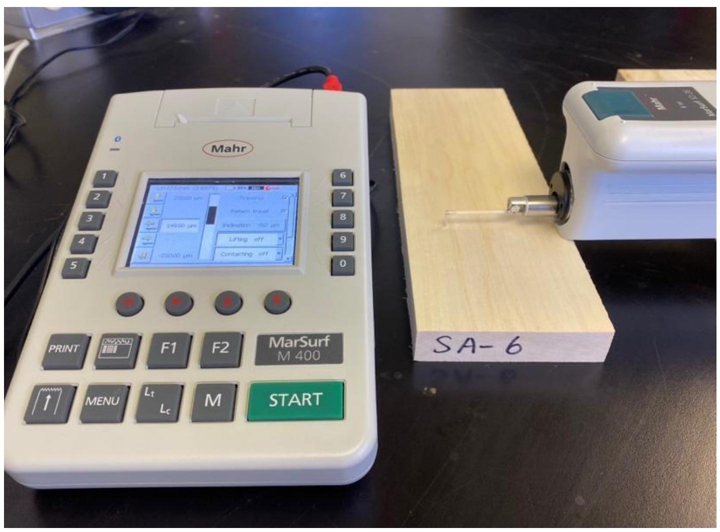
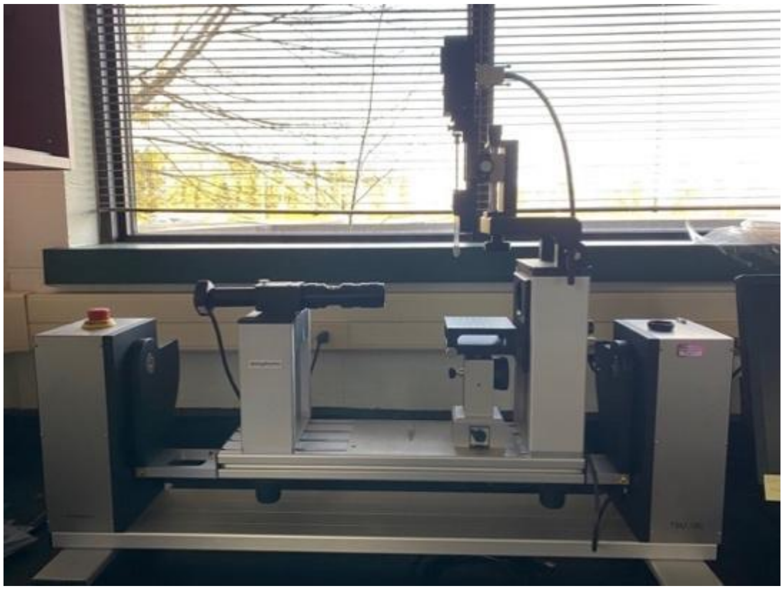


Figure 11 - Surface roughness machine (Model: M400).

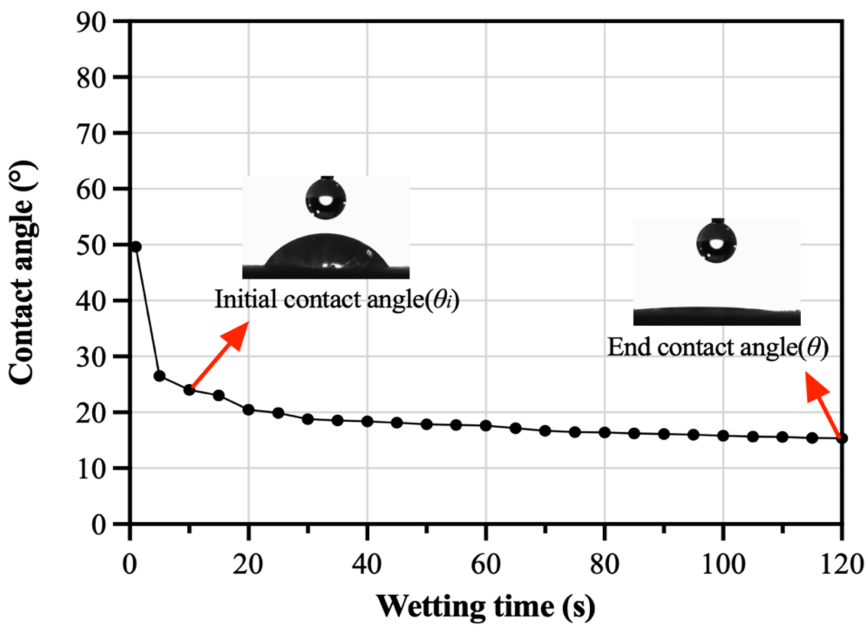
2.2.4.3. Surface Wettability

Good wetting is essential for strong adhesion, as it promotes better mechanical interlocking, molecular-level interactions, and secondary force interactions between the coating and the wood surface. To evaluate the wetting properties, analyses were conducted according to EN 828 "Determination by measurement of contact angle and surface free energy of solid surface" (EN 2013) with sessile drop water contact angle measurements conducted with Data Physics OCA 20 (DataPhysics Instruments GmbH, Germany), within 24 hours after machining treatments (Figure 12a, b). Small droplets (5 µl) of distilled water were added to the machined wood surfaces with an injection micro-syringe. A frame grabber recorded the changes in droplet profile during wetting. Contact angles of right and left angles of the drop's droplets were measured at intervals of 1s for a total duration of 120 s. All measurements were carried out with a view parallel to the orientation of wood fibres. Five replicate droplets were evaluated on each specimen for a total of 15 measurements for each machining treatment. Contact angle was calculated as an average of both sides of a droplet to compensate for horizontal variations. The initial contact angles θ_i recorded at the first 10 second after droplet deposition, and final contact angle at the end of 120 s were also recorded (Figure 12c).



a.

b.



c.

Figure 12 - Contact angle test: a. contact angle analyzer, b. direction for syringe, c. sketch for measuring contact angle (°).

2.2.4.4. Coating Adhesion Strength

Coating procedure:

The planed and sanded surfaces were coated within 6 hours of processing. Before spraying, the front of each specimen was cleaned with a dry cloth and positioned face-up to minimize air contact. At the room temperature, three layers of polyurethane waterborne coating (Brand: Varathane) were applied according to the manufacturer's instructions. After drying, the coating was lightly sanded with 220-grit sandpaper before applying an additional layer of coating.

Adhesion evaluation:

Surface coatings are essential for providing protection to wood and wood-based products. Understanding the adhesion mechanisms on wood surfaces and evaluating its strength are crucial to extend the service life of transparent film-forming coatings, especially in interior applications. The adhesion of the coating was assessed using a pull-off test in accordance with ASTM D4541 "Standard test method for pull-off strength of coatings using portable adhesion testers" (ASTM 2002). A DeFelsko PosiTest AT-A pull-off tester, with a maximum capacity of 24 MPa with a ± 1% full-scale accuracy, was employed (Figure 13a). Small 20-mm diameter dollies were adhered to the coated surface using a two-part epoxy resin mixed in a 1:1 ratio with hardener according to the manufacturer's instructions (Figure 13b). After 24 hours of curing at room temperature, the perimeters of the glued dollies were carefully incised to prevent failure propagation beyond the test area. The pull-off tests were conducted under controlled conditions of 20 ºC and 40 % RH. A cylindrical actuator connected to a hydraulic pump was positioned over the dolly head. Vacuum was gradually applied to the actuator at a rate below 1 MPa/s until the dolly separated. During the process, the maximum load and loading time were recorded and a corresponding diagram was displayed on the screen. The drag pointer on the pressure gauge recorded the maximum normal pull strength at the point of rupture. The adhesion strength (P) was calculated according to Eq. 4:

$$P = \frac{4F}{\pi d^2} \#(4)$$

where, F is the force at rupture (N), d is the diameter of the experiment cylinder (mm).

a.

b.

Figure 13 - Adhesion test: a. Pull-off adhesion test machine, and b. Test dollies glued on coated specimen surface.

2.2.4.5. Effects of Lumber Length, Knot Size, and Species on Mechanical Properties

After coating, two specimens from each group were selected, and 8 mm^3 cubes were prepared to observe the transverse surface. The coated surfaces were examined using a field-emission scanning electron microscope (JSM-6360LV, JEOL) at 15 kV. The cubes were mounted, with carbon coating on the sides and a gold layer on the surface to enhance observation. The evaluation focused on film thickness, interfacial gaps, coating penetration, and cell damage on the surface and subsurface.

2.3. Results and Discussion

2.3.1. *Physical Properties*

2.3.1.1. Dimensional Stability

Table 1 summarizes the average results from 32 wood block specimens compared to reference data from the Wood Handbook (USDA 2010). The tangential-to-radial shrinkage ratio was 1.2, compared to the reference value of 1.9. The average volumetric shrinkage was nearly identical at 11.6 % and 11.5 %, respectively. These suggest a good dimensional stability of aspen. The oven-dry aspen specimens had an average SG of 0.42.

Table 1 – Effect of the maximum knot size on the MSR-MOE_{min} and UTS

Data type	Directions				Volumetric (%)	SG
	Tangential (%)	Radial (%)	Longitudinal (%)	T/R		
Test results	6.1	5.2	0.1	1.2	11.6	0.42
Reference data (USDA 2010)	6.7	3.5	0.1	1.9	11.5	

2.3.2. *Mechanical Properties*

2.3.2.1. Surface Hardness

Table 2 gives the hardness results of aspen and spruce. Aspen wood showed a Brinell hardness of 22.51 MPa in the R direction, 30.5 % higher than that in the T direction. For comparison, black spruce had the hardness of 16.49 MPa in R direction, 8.9 % higher than that in T direction. The average MCs of aspen and black spruce at test were measured to be 11.3 % and 11.8 %, and average SG were 0.42 and 0.47, respectively. Overall, aspen had a slightly larger hardness than spruce.

Table 2 Surface Brinell hardness values of aspen and spruce in two directions.

Wood species	Brinell hardness (HB) (MPa)		MC (%)	SG
	Radial direction	Tangential direction		
Aspen	22.51 (14.20)	15.65 (7.21)	11.3	0.42
Black spruce	16.49 (4.43)	15.01 (3.83)	11.8	0.47

Numbers in parentheses are standard deviations.

2.3.2.2. Screw Withdrawal Resistance

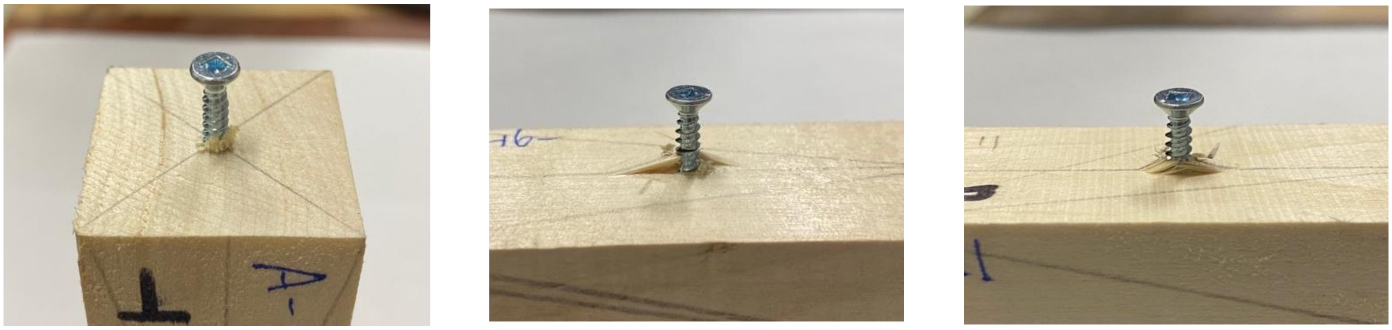
Table 3 presents the average screw withdrawal resistance, the standard deviation (SD), and the coefficient variation (CoV) in the R, T, and L directions of aspen wood. Results showed the highest average withdrawal resistance strength of aspen was in R direction (20.90 MPa), exceeded the T direction by 5.6 % and the L direction by 21.9 %, respectively. After testing, the average MC of aspen was 10.2 % with the average SG of 0.43.

Table 3 Screw withdrawal resistance of aspen in three directions.

Test direction	Withdrawal resistance (MPa)	MC (%)	SG
Radial	20.90 (3.09)	10.2	0.43
Tangential	19.72 (3.43)		
Longitudinal	16.33 (4.98)		

Numbers in parentheses are standard deviations.

All specimens with screws parallel to the grain (end grain penetration) failed due to plug shear between the wood and the outer diameter of the screw, as shown in Figure 14a. Withdrawal failure occurred in a thin shear layer in the wood surface penetrated by the screw threads, while the core of the connector and surrounding wood remained under pure axial stress. For specimens with screws installed into the side grain, the failure mode involved both splitting, due to tension perpendicular to the grain, and rolling shear, where the base material was lifted by the screw connector, as illustrated in Figure 14b. The final failure in these specimens was marked by cross-grain shear or splitting of the superficial fibre layer, as depicted in Fig. 14(c).



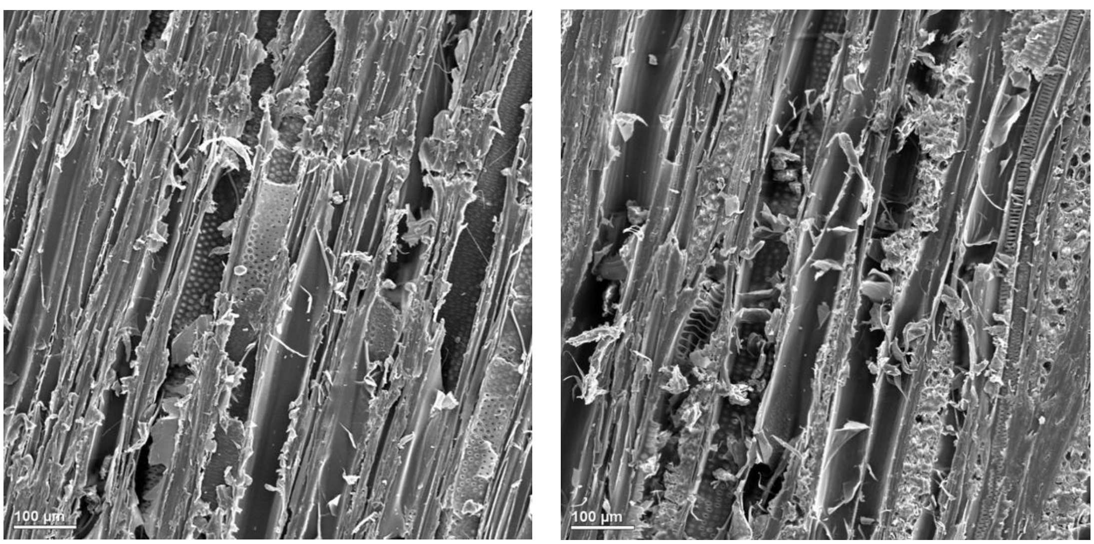
a. b. c.

Figure 14 Failure modes of specimens in three directions: a. L, b. T, and c. R direction.

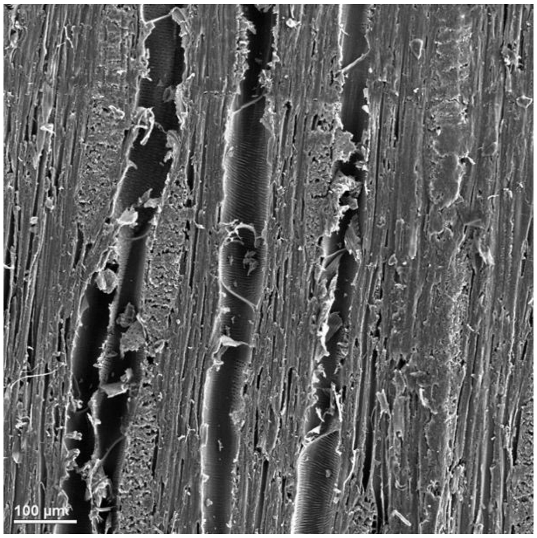
2.3.3. *Machining Properties*

2.3.3.1. Machining Surface Microscopic Evaluation

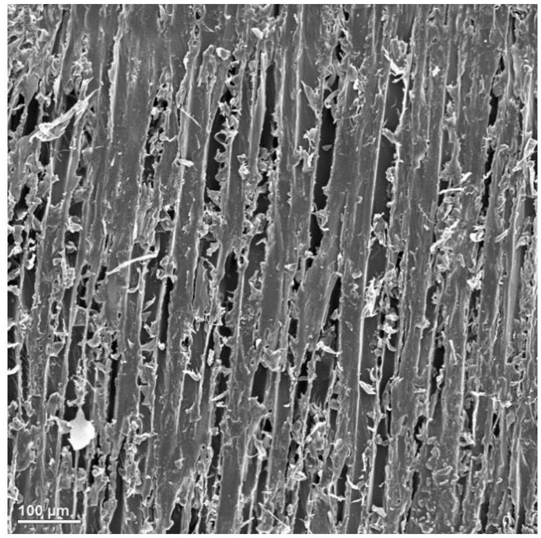
Scanning electron microscopic (SEM) micrographs showed that sanded surfaces were rougher than planed ones (Figure 15). Abrasive tearing on sanded surfaces caused cell-wall fibrillation, with visible scratches from the abrasive grains (Figure 15b). Sanding also blocked the lumens of rays and fibres, and open vessels were rarely seen. In contrast, planing produced surfaces with more open cells, especially vessels (Figure 15a), which could give paths for following coating penetration. However, fibres and ray lumens were less visible on planed surfaces due to superficial crushing.



Trembling aspen Yellow poplar

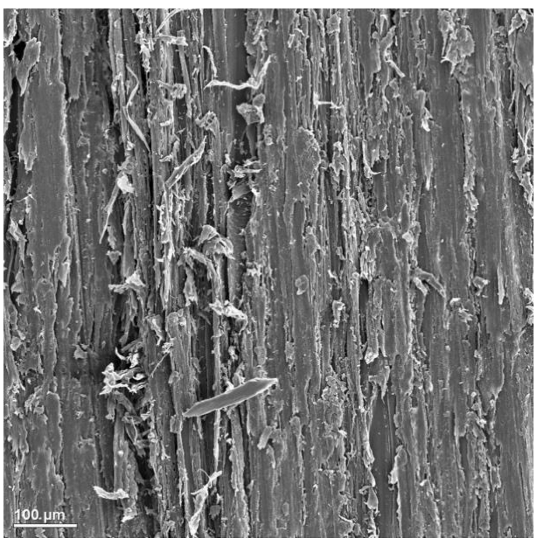


Silver maple



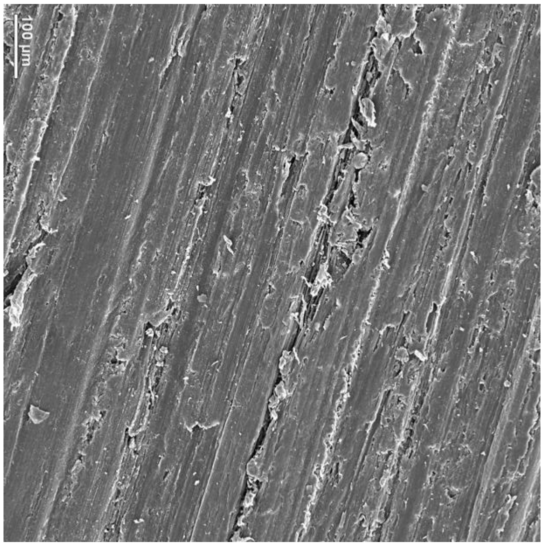
Eastern white pine

a. Planed group (scale=100 μm).

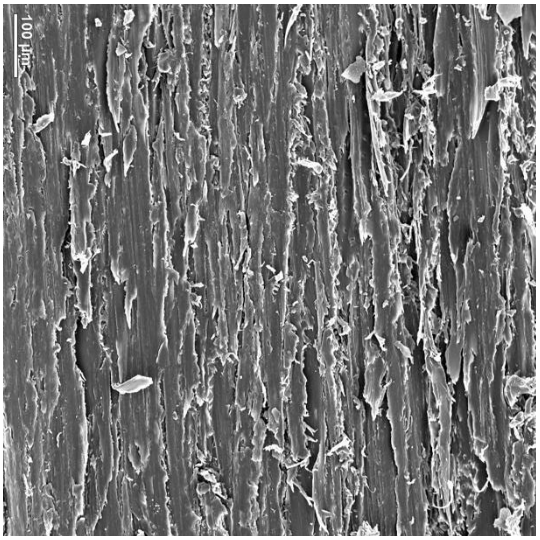


Trembling aspen

Yellow poplar



Silver maple



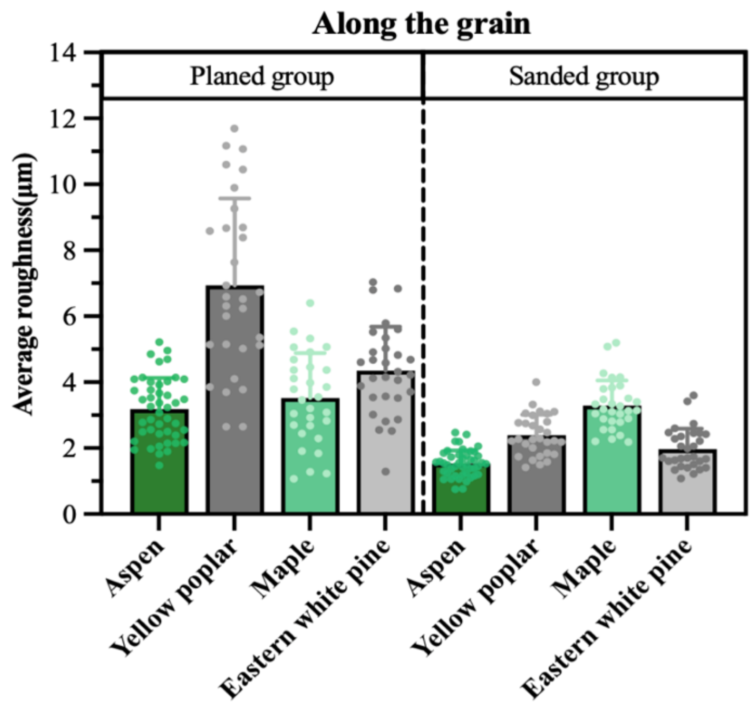
Eastern white pine

b. Sanded group (scale =100 μm, except yellow poplar = 200 μm).

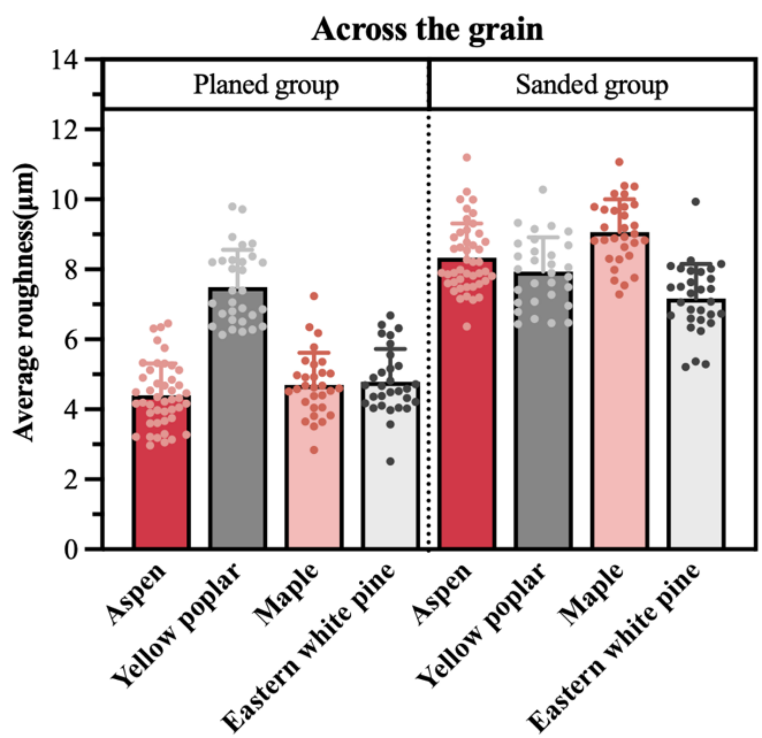
Figure 15 - Tangential SEM micrographs of four wood species surfaces produced by planing (a) and sanding (b).

2.3.3.2. Surface Roughness

The roughness evaluation results are shown in Figure 16. Significant differences in average roughness (R_a) are observed in the direction across the wood grain, with sanded surfaces being rougher than planed ones. As expected, roughness was more pronounced in the direction cross to the wood grain movement (Table 4). Maple had the highest average roughness at 9.07 μm, followed by aspen at 8.33 μm, and yellow poplar and eastern white pine at 7.94 μm and 7.16 μm, respectively. For planed surfaces, roughness remained consistent across both directions, with aspen, maple, and pine showing values of 4.40 μm, 4.70 μm, and 4.79 μm. Yellow poplar, however, had a significantly higher roughness of 7.50 μm, well above the other three species.



a.



b.

Figure 16 – Surface roughness values of four wood species examined in this study after planing and sanding in two directions (a. along the grain; and b. across the grain).

Table 4 – ANOVA results of surface roughness.

Factors	Sum of squares	DF*	MS*	F-value	*p*-value
Wood species (A)	267.91	3	89.30	73.55	<0.0001
Test directions (B)	1459.65	1	1459.65	1202.17	<0.0001
Machining methods (C)	11.18	1	11.18	9.21	0.002
Interaction (AB)	30.57	3	10.19	8.39	<0.0001
Interaction (AC)	294.00	3	98.00	80.71	<0.0001
Interaction (BC)	809.09	1	809.68	666.86	<0.0001
Interaction (ABC)	5.54	3	1.85	1.52	0.208
Residual	636.22	524	1.21		
Total	3685.31	539			

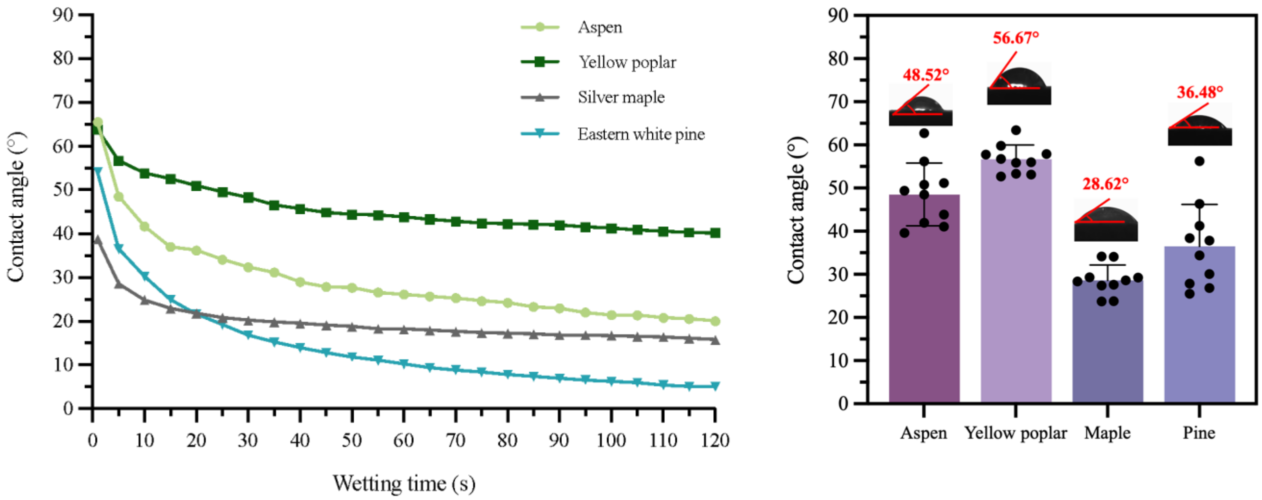
*DF is degrees of freedom and MS is mean square.

2.3.3.3. Surface Wettability

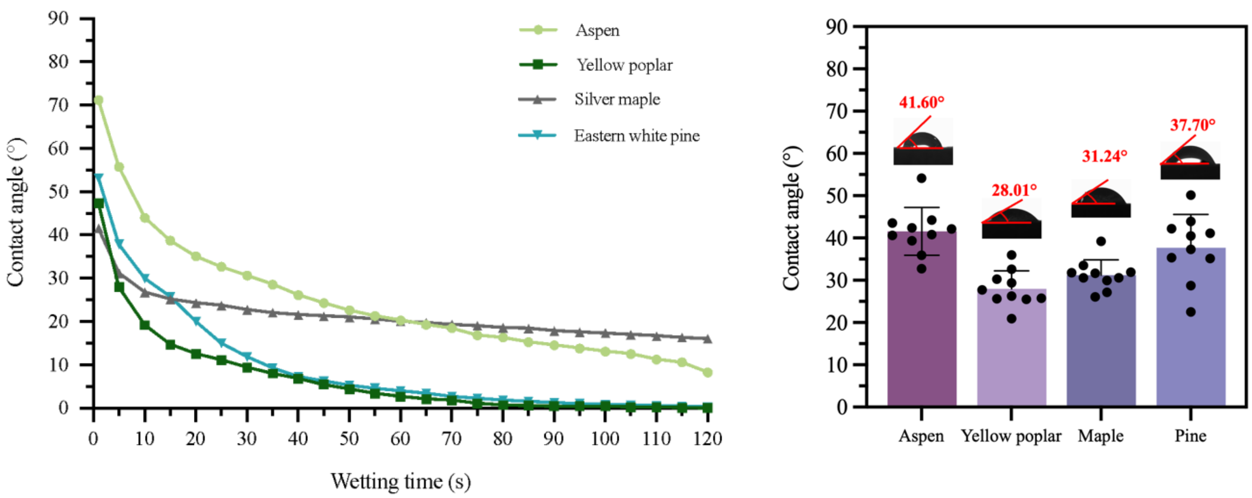
The results of the wetting tests are summarized in Figure 17. The SCA software was used to record the dynamic changes in contact angle over time, while a video captured the process. Figure 17 shows the screenshots of the initial contact angle from the recording videos. Dynamic contact angle dependence on time evaluation and initial angle are also presented in Fig.17. Water spread more along the grain, consistent with observations by Shi and Gardner (2001). Initial contact angles (θ_i) were higher on planed surfaces compared to sanded ones. A contact angle of less than 90 degrees indicates that the material exhibits hydrophilic behavior, a low contact angle indicates good hydrophilic, while a high contact angle suggests poor hydrophobic.

For aspen, the average of initial angle was 48.5° on planed surfaces and 41.6° on sanded surfaces. Yellow poplar showed the largest difference, with an average planed angle of 56.7°, which was 50.6 % higher than the sanded angle. In contrast, maple and eastern white pine showed minimal differences between planed and sanded surfaces.

Sanded surfaces promoted better water spreading due to fibre wise abrasive scratches (Figure 17 b), which accelerated water conduction along the grain. This effect was not observed on planed surfaces. Similar acceleration of liquid spreading due to surface scratches has been reported in previous studies (Garrett 1964 and Walinder 2000). Over time, by the end of the 120-second test, yellow poplar and eastern white pine exhibited the most significant changes, with their average contact angles dropping to 0°, followed by aspen at 8.3°, which shows a high hydrophilicity. Silver maple had the highest remaining contact angle at 16.1°.



a. Planing group



b. Sanding group

Figure 17 – Dynamic contact angle dependence on time by two machining methods for four wood species (left); initial contact angle θ_i (right).

2.3.3.4. Coating Adhesion Strength

Figure 18 shows the average adhesion strength for polyurethane-coated specimens. Adhesion was stronger on sanded surfaces. Sanded maple had the highest average adhesion strength at 5.39 MPa (0.49), followed by yellow poplar at 4.78 MPa (0.52), aspen at 3.80 MPa (0.46), and eastern white pine at 3.81 MPa (0.35). In the planed group, the average adhesion strength of aspen was 3.51 MPa, which was 7.6 % lower than sanded aspen. This indicates that aspen after sanding tend to have a higher coating strength than planing. According to Sandlund (2004) and Gardner (2005), a rougher surface increased the physical contact area, allowing the coating to adhere more effectively to the wood substrate.

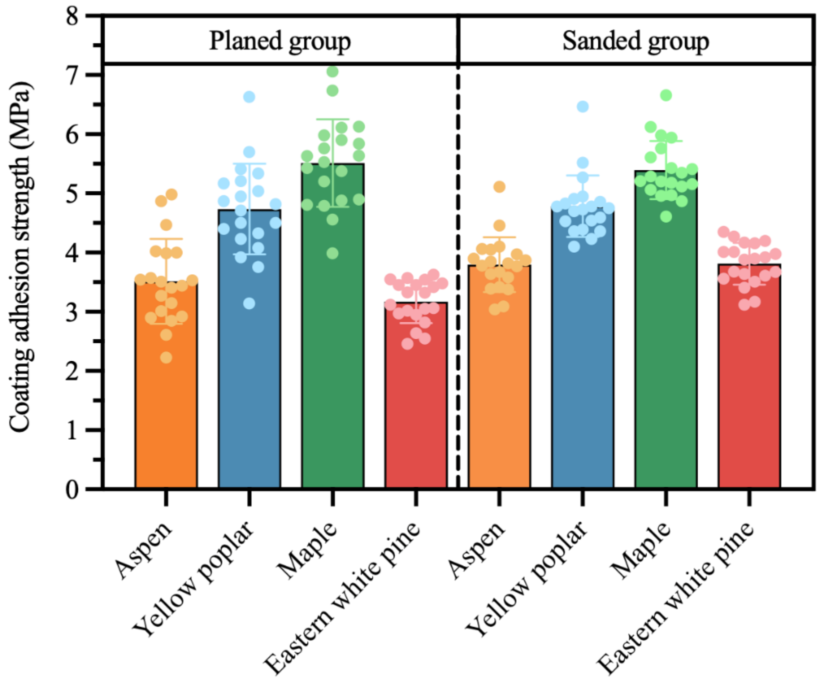


Figure 18 – Coating adhesion strength results after planing and sanding.

a. b.

Figure 19 – Pull-off test dollies showing the coating interfaces holding fibres pulled out from the surface. a: the representative dolly pulled-off from sanded surfaces (S); b: four dollies pulled-off from planed surfaces (P).

2.3.3.5. Coating Penetration Microscopic Evaluation

Figure 20 presents the penetration depth in the transverse direction of coated specimens for two machining methods and four wood species. The penetration depth was measured using images captured by a scanning electron microscope and processed with Photoshop and ImageJ software. Penetration depth was determined by selecting five random points on the specimen surfaces using these ImageJ, and the average depths were then calculated (Figure 21).

Eastern white pine exhibited the largest difference between planing and sanding, with the average penetration depth increasing from 54.05 µm (planed) to 69.57 µm (sanded), with a 22.51% increase. This result aligned with contact angle and coating pull-off adhesion tests, where pine had the lowest contact angle (0°) after 120 s. Aspen specimens had the greatest average penetration depth in the planed group at 51.57 µm, indicating the best wettability among the four species after planing. In contrast, other species, such as yellow poplar, showed the average penetration depths of 26.83 µm (planed) and 43.79 µm (sanded), while maple had 39.67 µm (planed) and 39.34 µm (sanded), with minimal variation. These results indicated that the polyurethane coating penetrated deeper in the sanded specimens compared to the planed specimens.

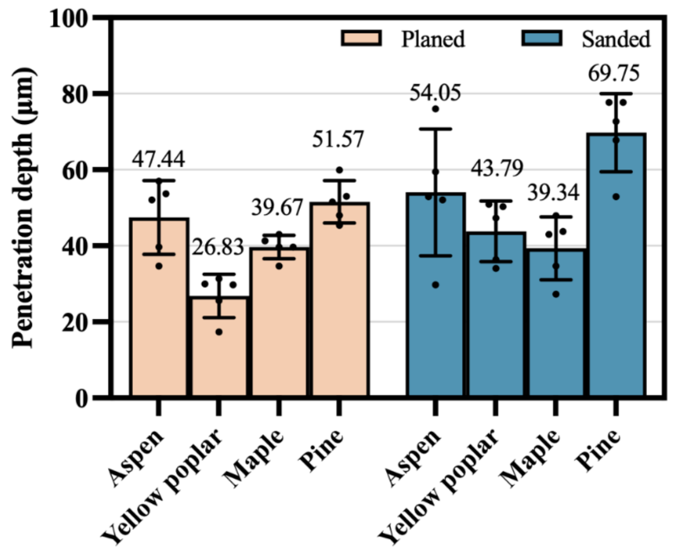


Figure 20 – Comparison of coating penetration depth.

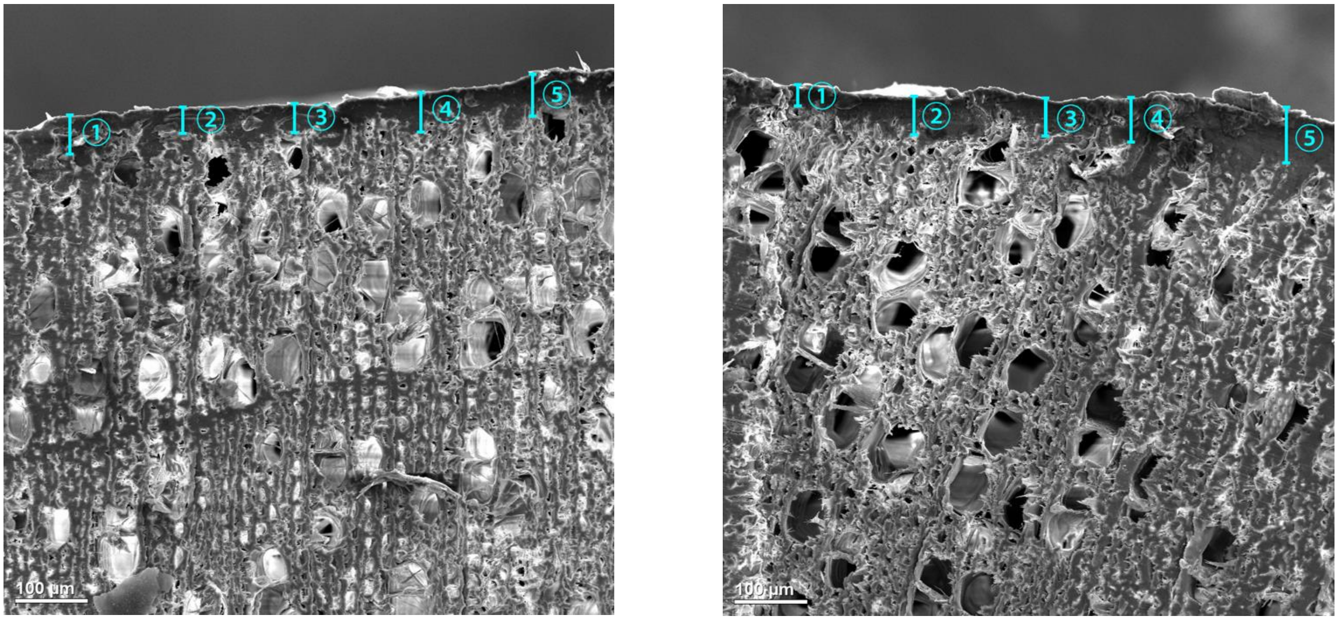


Figure 21 – Transverse SEM micrograph of coated aspen specimens (Left is planed and right is sanded).

3 NON-STRUCTURAL WOOD PRODUCTS FOR INTERIOR USE

3.1. Trembling Aspen Flooring

3.1.1. *Material*

The materials used for products fabrication and testing were sourced from La Crete, Alberta. The lumber was kiln-dried and graded as "No. 2 and better," with nominal dimensions of 2 × 4 (38 mm × 89 mm) and lengths of 8.5 ft. and 12 ft. Surface defects (such as sound or unsound knots, stain or fuzzy grain) were visually inspected, ensuring that at least a 6 ft. section of each piece was clear wood.

3.1.2. *Manufacturing*

Thirty (30) pieces randomly selected 8.5 ft. lumber was prepared for interior flooring production. The flooring was manufactured in the production line of Colonial Manufacturing Ltd., a local producer in Fredericton, New Brunswick, who also supplies an equivalent quantity of flooring made from silver maple, a species commonly used in producing flooring products (Figure 22).

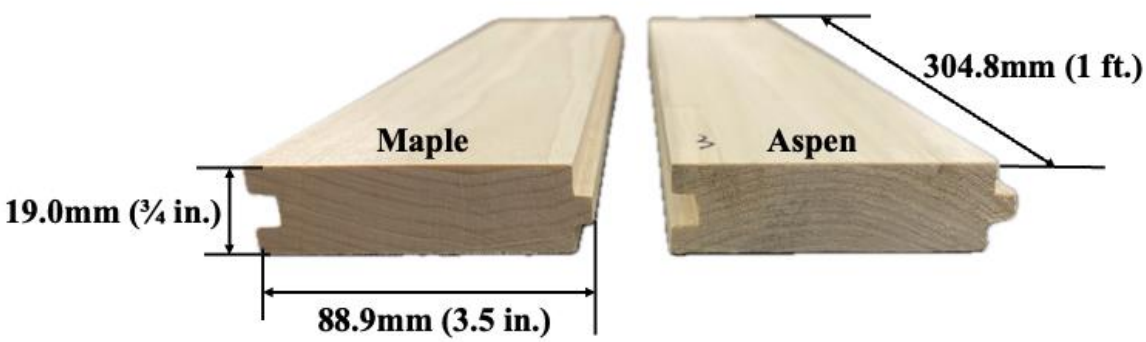


Figure 22 – Dimensions of flooring specimens.

3.1.3. Testing

3.1.3.1. Surface Hardness

The surface hardness of the flooring specimens was evaluated using the Brinell hardness method, following the same experimental setup and testing machine described in Section 2.2.3.1 for aspen wood surface hardness. The dimension of each specimen was 19 mm × 89 mm × 305 mm (0.8 in. × 3.5 in. × 12.0 in.) (thickness × width × length) in dimensions, was selected from the flooring products. The steel ball was pressed into specimen surface, and the maximum indentation depth in the radial direction was recorded (Figure 23). The Brinell hardness was then calculated from these measurements.

Figure 23 Setup for testing the surface hardness of a flooring specimen.

3.1.3.2. Moisture Content and Specific Gravity

After conducting flooring surface hardness test, a 1-inch-thick wood block was cut from each specimen for MC and oven-dry SG determination, in accordance with ASTM D4442 (ASTM 2020).

3.1.4. Results and Discussion

3.1.4.1. Surface Hardness

Aspen flooring products were tested, with silver maple as the comparison species. Based on indentation depth values, surface resistance to indentation was evaluated (Figure 24). A greater indentation depth indicates lower resistance. As shown in Figure 24a, the average indentation depth in aspen flooring is 2.27 mm, 59.5 % deeper than that of maple flooring, which averages in 0.92 mm, suggesting the surface hardness of maple flooring was significantly higher than that of aspen flooring.

Based on Figure 24b, the average Brinell hardness of maple flooring is 33.44 MPa, which is 59.8 % greater than that of aspen flooring (13.47 MPa). After testing, the average MCs of aspen and maple were measured to be 8.9 % and 8.1 %, and average SG values were 0.43 and 0.70, respectively.

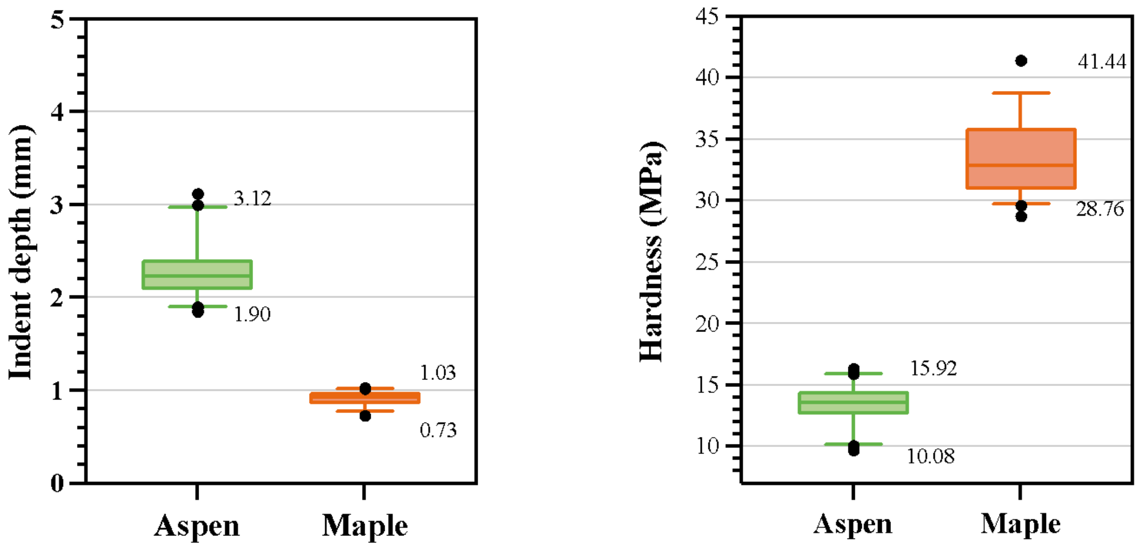
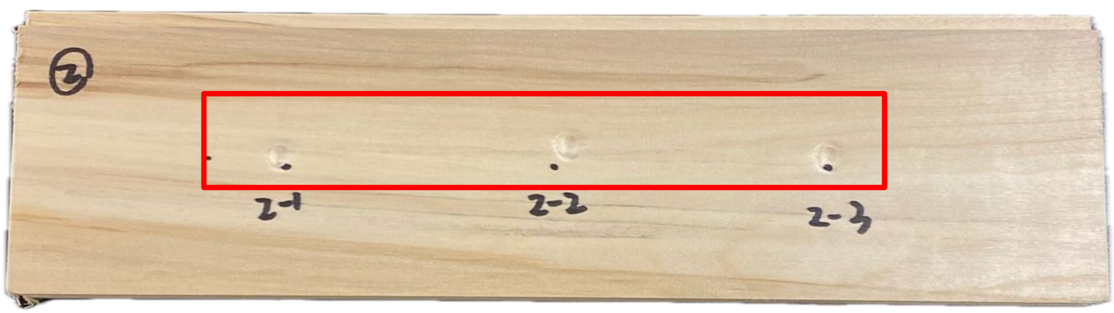


Figure 24 - Indentation depth (a) and surface hardness (b) of aspen and maple flooring specimens.



a.

b.

Figure 25 - Surface indentation after testing (a) aspen, (b) maple.

3.1.4.2. Yield Analysis of Trembling Aspen Flooring

The yield flowchart for aspen flooring is shown in Figure 26. La Crete Sawmill Ltd. reported a 51.2 % yield from logs to kiln-dried, visually graded "No. 2 and better" lumber, which was then sent to Colonial Manufacturing Ltd. for moulding production. Colonial Manufacturing Ltd. focuses on high-grade, defect-free, fully customized products, calculating yields based on the clear wood portion. Clear wood constitutes approximately 68.8 % of the flooring. As a result, the final yield of the aspen molding product was approximately 35.2 %.

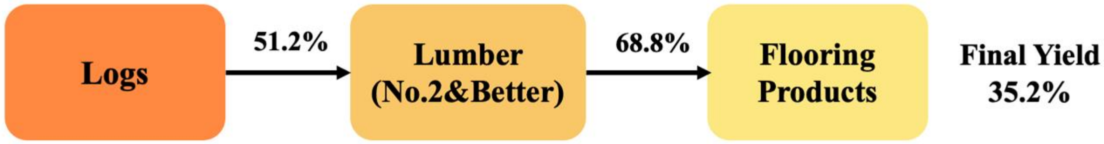


Figure 26 - Estimation of the yield in the production of aspen flooring from logs to flooring products.

3.2. Trembling Aspen Moulding

3.2.1. Materials and Manufacturing

Ten (10) pieces of 8.5 ft. long aspen lumber pieces were processed into moulding with a common ‘Crown’ profile. Additionally, the manufacturer provided moulding products with the same profile made from two commonly used species for comparison: a softwood, eastern white pine and a hardwood, American yellow poplar (Figure 27).

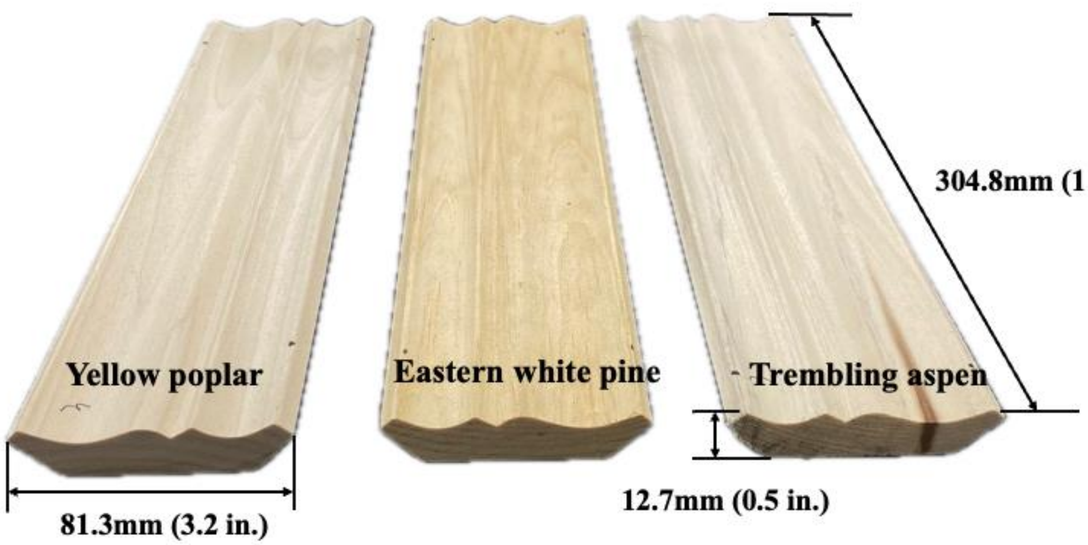


Figure 27 - Dimensions of moulding specimens.

3.2.2. Testing

3.2.2.1. Screw Withdrawal Resistance

The screw withdrawal resistance test for the moulding products was conducted using the same size of screws, same test procedure and machine described in Section 2.2.3.2 for screw withdrawal resistance in aspen wood, following ASTM D1761 “Mechanical fasteners in wood and wood-based materials” (ASTM 2020). The dimensions of the moulding specimens were 12.7 mm × 81.3 mm × 150.0 mm (0.5 in. × 3.2 in. × 6.0 in.) (thickness × width × length) in dimensions. Due to the irregular shape of the moulding products, testing was conducted along the geometric centre, with all specimens pre-drilled. According to standard requirements, the pre-drilled hole was made at 70 % of the screw diameter, resulting in 2.32 mm (0.09 in.) hole. Specimens were tested at a thickness of 13 mm (0.5 in.). Since the specimen thickness did not meet the specified nine times the screw diameter for proper penetration, the screws were totally inserted through the specimens according to standard (Figure 28). Aspen, yellow poplar, and eastern white pine were included as comparison species, with six specimens per species and two test points per specimen, yielding 36 total data points. The specimens were tested by means of an Instron universal test machine (Model: 3367), with a constant pulling speed of 3 mm/min applied until the screws were completely separated from specimens (Figure 29). After the tests, the screw diameter and specimen thickness were recorded, and the screw withdrawal resistance in the radial direction was calculated.

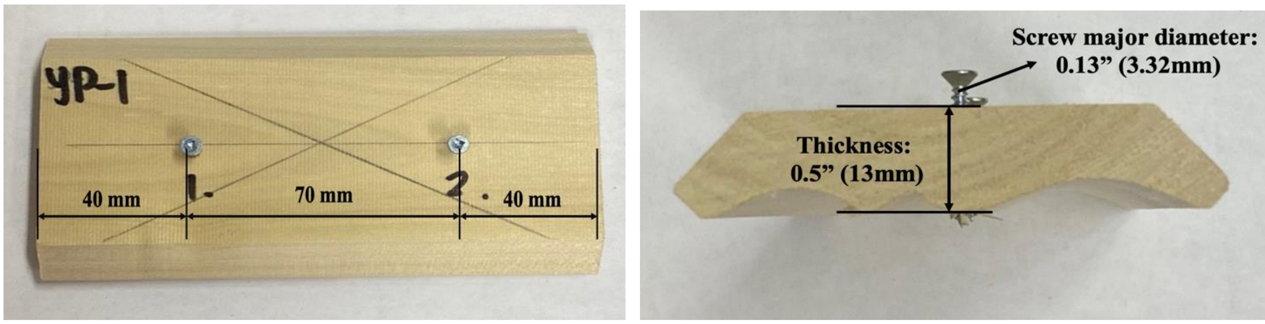


Figure 28 - Geometry dimensions for moulding specimens.

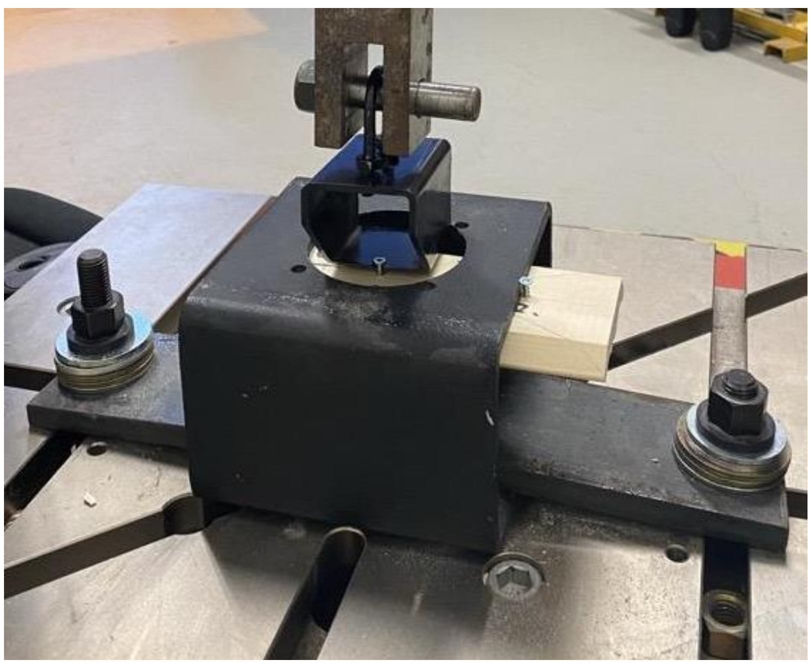


Figure 29 - Setup for testing the screw resistance of a moulding specimen.

3.2.2.2. Moisture Content and Specific Gravity

After conducting moulding screw withdrawal resistance test, a 1-inch-thick wood block was cut from each specimen for MC and oven-dry SG determination, in accordance with ASTM D4442 (ASTM 2020).

3.2.3. Results and Discussion

3.2.3.1. Screw Withdrawal Resistance

Figure 30 presents the withdrawal resistance results for three wood species. It shows that yellow poplar has the highest average withdrawal resistance at 26.93 MPa, while aspen is 13.0 % lower than that of yellow poplar. Eastern white pine has the lowest average screw withdrawal resistance at 19.92 MPa and the smallest standard deviation at 0.73 MPa. Yellow poplar exhibits the largest standard deviation at 5.31 MPa, 36 % higher than aspen's 3.60 MPa. The maximum withdrawal load follows the same trend among the three species.

For specimens with screw pulling-out of direction perpendicular to the grain, the final failure modes for these specimens were accompanied with the cross-grain shear or splitting of superficial first fibre layer of the block as shown in Figure 31. Specimens of yellow poplar and aspen showed a noticeable tendency for surface fibre pull-up.

After testing, the average MC of aspen was 10.0 % with an average SG of 0.42. The average MC values of yellow poplar and eastern white pine were 8.4 % and 10.7 %, respectively. The average SG of yellow poplar was the highest 0.48 and eastern white pine had the lowest at 0.40. Thus, an increased SG of the specimens can influence the higher screw withdrawal resistance strength.

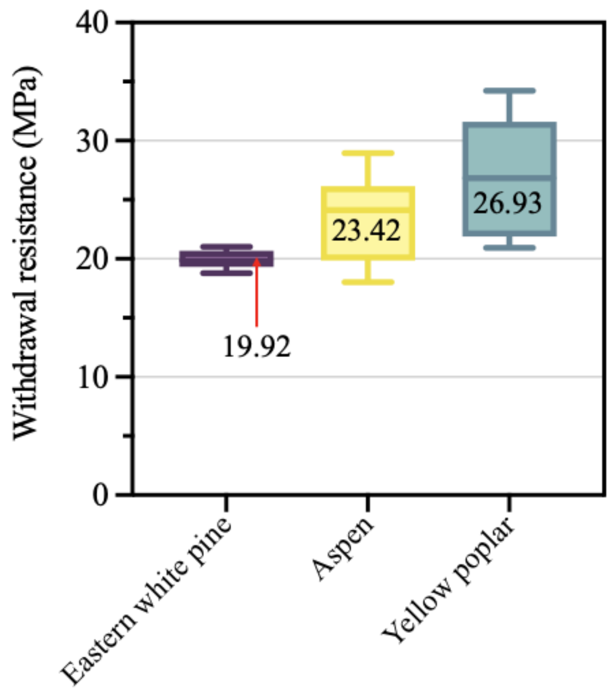


Figure 30- Comparison of average withdrawal resistance for moulding specimens.

a.

b.

c.

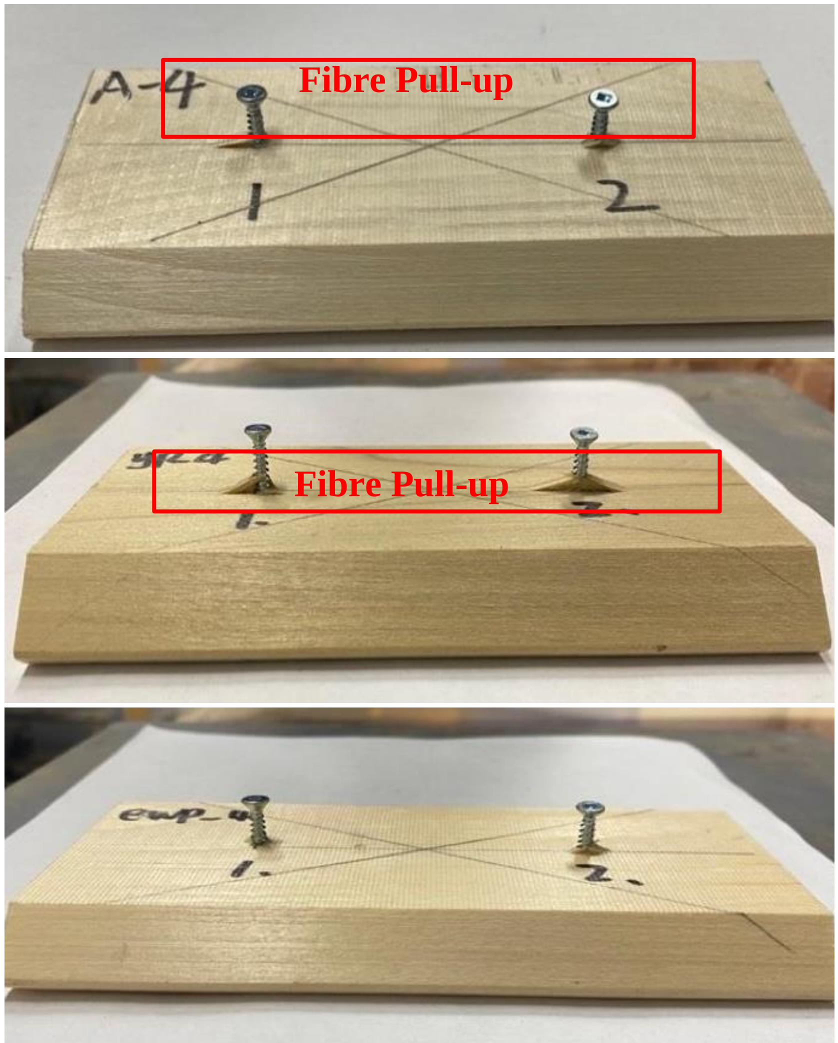


Figure 31 - Failure modes of moulding specimens in different species: a. aspen, b. yellow poplar, and c. eastern white pine.

3.2.3.2. Yield Analysis of Trembling Aspen Moulding

The yield flowchart for aspen moulding is shown in Figure 32. La Crete Sawmill Ltd. reported a 51.15 % yield from logs to kiln-dried, visually graded “No. 2 and better” lumber, which was then sent to Colonial Ltd. for moulding production. Eventually, aspen moulding yielded 49.7 %, due to unsound knots and severe fuzzy grain, which negatively affected appearance. Colonial Manufacturing Ltd. focuses on high-grade, defect-free, fully customized products, calculating yields based on the clear wood portion. As a result, the final yield of the aspen moulding product is approximately 25.4 %.

Figure 32 - Estimation of the yield in the production of aspen moulding from logs to moulding products.

4 NON-STRUCTURAL WOOD PRODUCTS FOR EXTERIOR USE

4.1. Trembling Aspen Siding

4.1.1. Materials and Manufacturing

Thirty (30) pieces of 8.5 ft. long, 2×4 aspen lumber were randomly selected and sent to Cape Cod Finished Wood Siding Ltd., Bedford, Nova Scotia. The manufacturer produced 40 finished siding pieces with dimensions of 38 mm × 89 mm × 2590 mm (thickness × width × length) in dimensions, featuring a “channel” profile. Additionally, the manufacturer provided 10 finished Spruce-Pine-Fir (S-P-F) siding, a species that commonly supplied to the market, along with unfinished aspen and S-P-F siding, which were used as comparison groups in subsequent testing (Figure 33). It was found that the aspen siding developed extensive localized fuzzy grain during the production. Cutting 2×4 lumber into 1×4 with a bandsaw affected the surface finishing process, significantly reducing surface quality (Figure 34).

Figure 33 – Finished exterior siding specimens made of S-P-F (left) and aspen (right).

Figure 34 - Fuzzy grain on aspen siding surface.

4.1.2. Testing

4.1.2.1. Testing Procedures

After fabrication, the exterior siding products were conditioned in the chamber for about two months. Prior to testing, they were grouped and cut to the required lengths. Figure 35 illustrates the testing procedure.

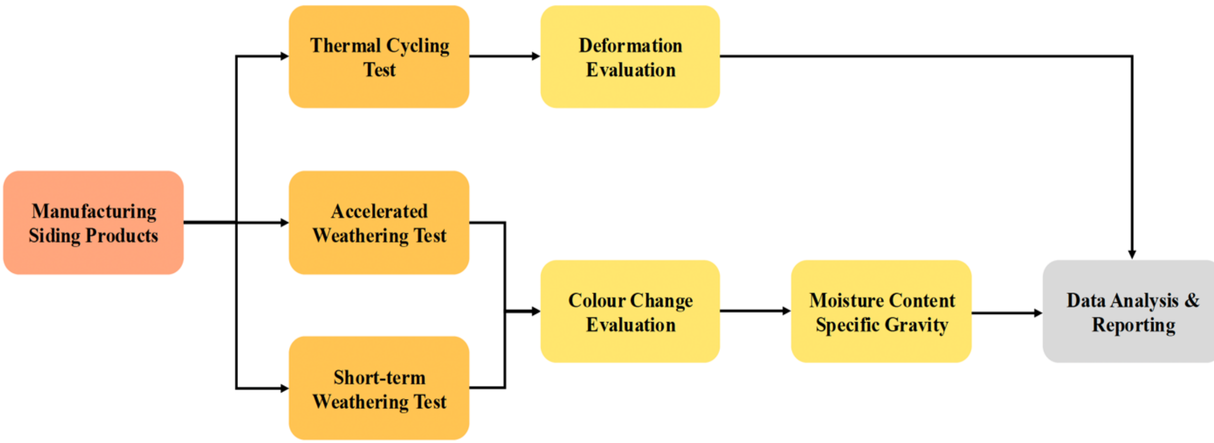


Figure 35 - Testing procedure for exterior siding specimens.

4.1.2.2. Thermal Cycling Weathering Test

Prior to testing, 1-inch-thick strapping was nailed to 4 ft. × 6 ft. frame (width × length), at 16-inch vertical intervals (Figure 36). According to the manufacturer's instructions, board specimens (4 - 6 ft. long) were horizontally attached to the strapping.

Figure 36 - Siding specimens mounted on a frame with both sides exposed.

In this study, siding specimens were exposed to four climatic conditions, including kiln dry, water spray, frost, and room temperature treatments following the "freeze-soak-thaw" cycle developed by the Wood Science Technology Centre (WSTC) at the University of New Brunswick (WSTC 2023), which was modified with reference to ASTM D6944 "Standard Practice for Determining the Resistance of Cured Coatings to Thermal Cycling" (ASTM 2015). Each cycle comprised four stages: (1) 1 hour of water spray, (2) 6 hours at 50 °C in the kiln, (3) 16 hours of freezing at -20°C, and (4) 1 hour of thawing at 23°C. During the daytime, water spray and kiln drying alternated in 6 cycles, each consisting of 8 minutes of water spray followed by 52 minutes of kiln drying. At least 200 ml of water was applied to the siding surface during each spray, ensuring no visible drops or stains remained on the specimens. After 6 cycles of water spray and kiln drying, the siding was frozen for 16 h, then thawed for 1 hour. The complete one-cycle treatment schedule is detailed in Figure 37.

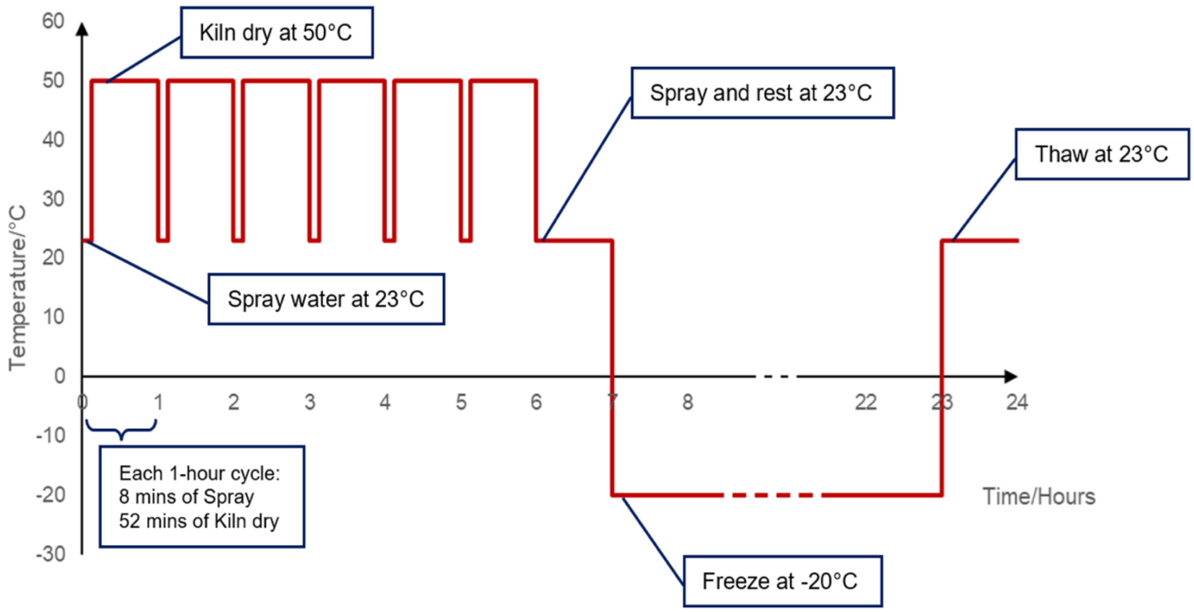


Figure 37 - Freeze-soak-thaw cycle schedule for a complete cycle.

4.1.2.3. Accelerated Weathering Test

An accelerated weathering test was also conducted to assess the durability of aspen siding by simulating outdoor environment, using S-P-F as a comparison species. The test followed ASTM G155 “Standard Practice for Operating Xenon Arc Lamp Apparatus for Exposure of Materials” (ASTM 2021). The specimens were exposed to accelerated weathering using a weather-o-meter (Model: Atlas Ci4400), as shown in Figure 38.

Figure 38 - The weather-o-meter used in this study.

Two factors of interest were determined: wood species and surface finishing. The dimensions of each specimen were 25.4 mm × 87.5 mm × 140.0 mm (1 in. × 3.4 in. × 5.5 in.) (thickness × width × length) in dimensions. Figure 39 illustrates a complete test cycle based on ASTM G155 (ASTM 2021). Each cycle of the accelerated weathering test lasted 120 minutes, comprising 102 minutes of light exposure followed by 18 minutes of light exposure with water spray. The full test consisted of 1000 cycles, totaling 2000 hours, with exposure conditions detailed in Table 5. To monitor and assess changes throughout the testing process, the specimens were periodically taken out for measurements of colour, mass, and dimensions at 50, 250, 500, 1000, and 1500 hours.

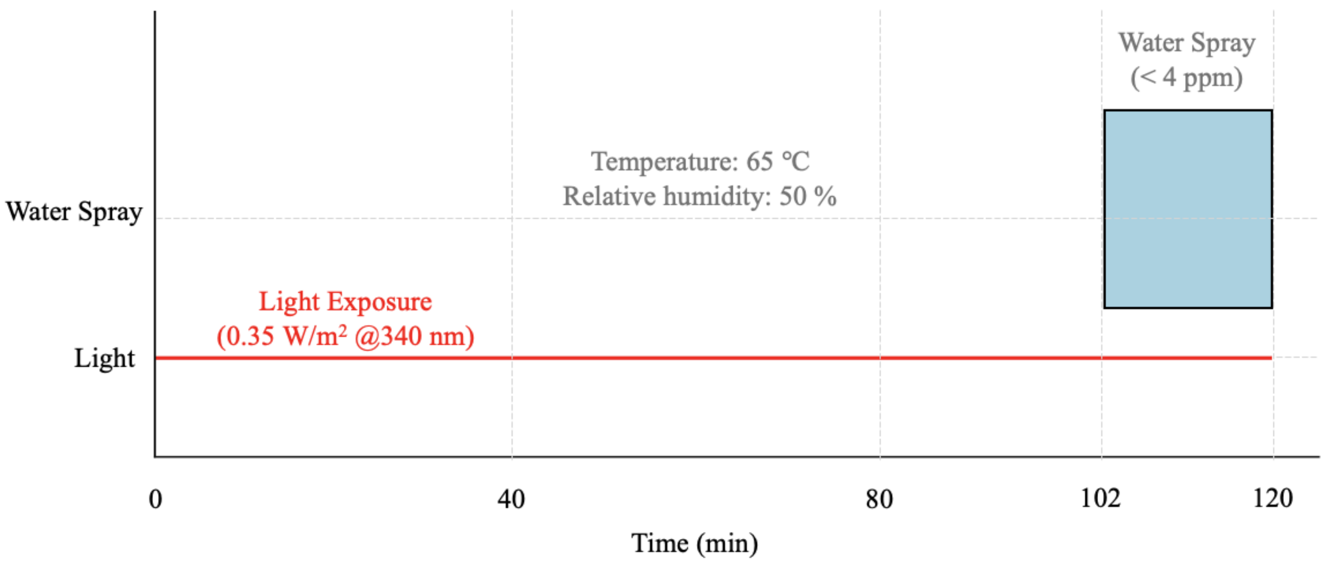


Figure 39 - Schematic of a complete single weathering treatment cycle in this study.

Figure 40 - Setup for testing in weather-o-meter of siding specimens.

Table 5 - Exposure conditions of the accelerated weathering test.

Phase	Irradiance and Wavelength	Exposure Treatment	Black Panel Temperature	RH	Water Purity
1		102-min light	65°C	50%	-

2	0.35 W/m2 @340nm	18-min light and water spray	-	-	< 4 ppm

After exposure, the specimens were evaluated based on changes in dimensions, colour, and the occurrence of checks in wood. The colour was recorded using a colorimeter (Model: BYK spectro2guide). In this study, the CIELAB colour space was used to assess colour change during the testing process. The CIELAB colour space defines colour using three coordinate axes: L^* for lightness (0-100, 0 for black, 100 for white), a^* for the position on the green-red axis (negative for green, positive for red), and b^* for the position on the blue-yellow axis (negative for blue, positive for yellow) (Tomak 2018). The colour difference (ΔE^*) before and after the weathering test, which can be calculated using Eq. 6, was used to evaluate the colour changes resulting from the weathering test (Machova 2019).

$$\Delta E = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2} \#(6)$$

where, L_1*& L_2, a_1*& a_2, b_1*& b_2, represent the L, a and b values before and after the weathering treatment, respectively.

4.1.2.4. Short-term Weathering Test

In this test, specimens were selected and cut from siding products manufactured. These specimens were then nailed to a frame and positioned on a rack in the pole yard near to the WSTC with one wide face exposed at a 45-degree angle facing south (Figure 41), according to ASTM G7 "Standard practice for atmospheric environmental exposure testing of non-metallic materials" (ASTM 2021). Specimens were inspected biweekly over four months. Surface colour changes (ΔE) were measured and calculated using a BYK-Gardner GmbH spectro2guide colourimeter (Germany) and reported as CIELAB L^*, a^*, and b^* values, calculation refers to Section 4.1.2.3 (Figure 42).

Besides surface colour change, the surface defects including cracks and splits, were measured with a caliper, and visual inspections were conducted for new defects. These observations were used to assess the colour and shape changes in the specimens during the natural weathering treatment after the initial coating application.

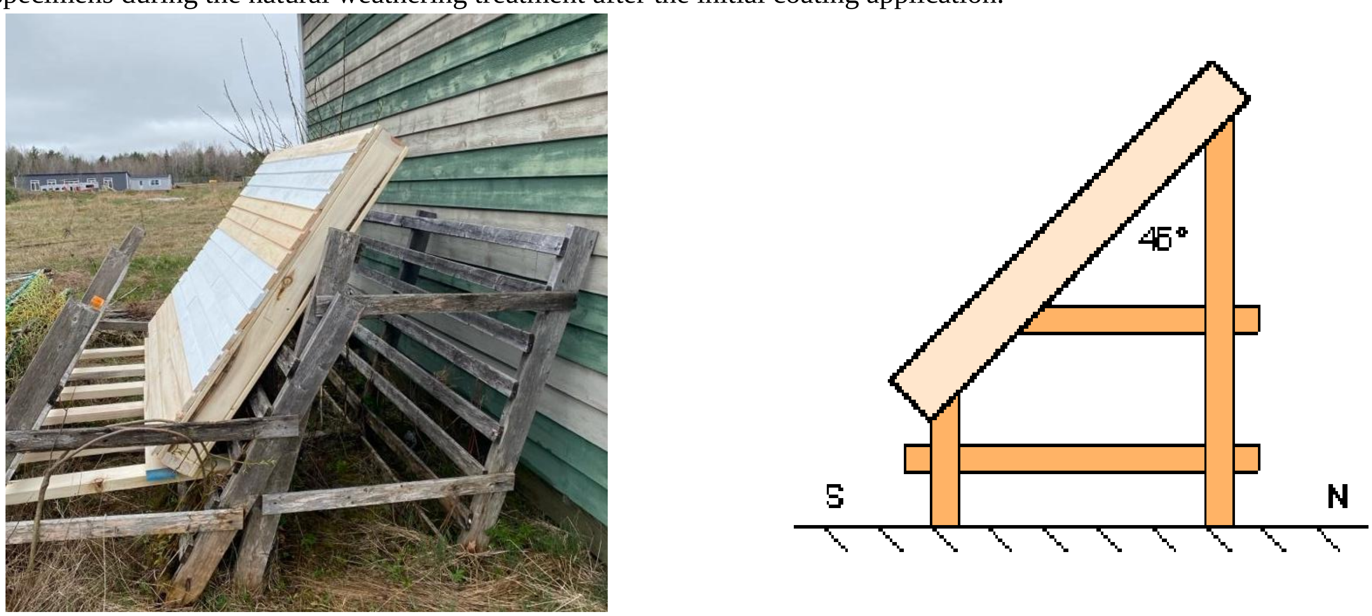


Figure 11 - Natural weathering of finished and unfinished siding specimens of two wood species at a 45° south-facing angle: testing site (left) and setup sketch (right).

Figure 42 – Colourimeter used (left) and measurement of surface color (right).

The site used in this natural weathering study experiences a humid continental temperate climate with four distinct seasons and significant temperature variations. Winters are cool and wet, while summers are warm and dry, often with high humidity. The average annual rainfall is approximately 1118 mm, mainly during summer, and monthly temperatures range from 2 °C to 20 °C (Figures 43 and 44).

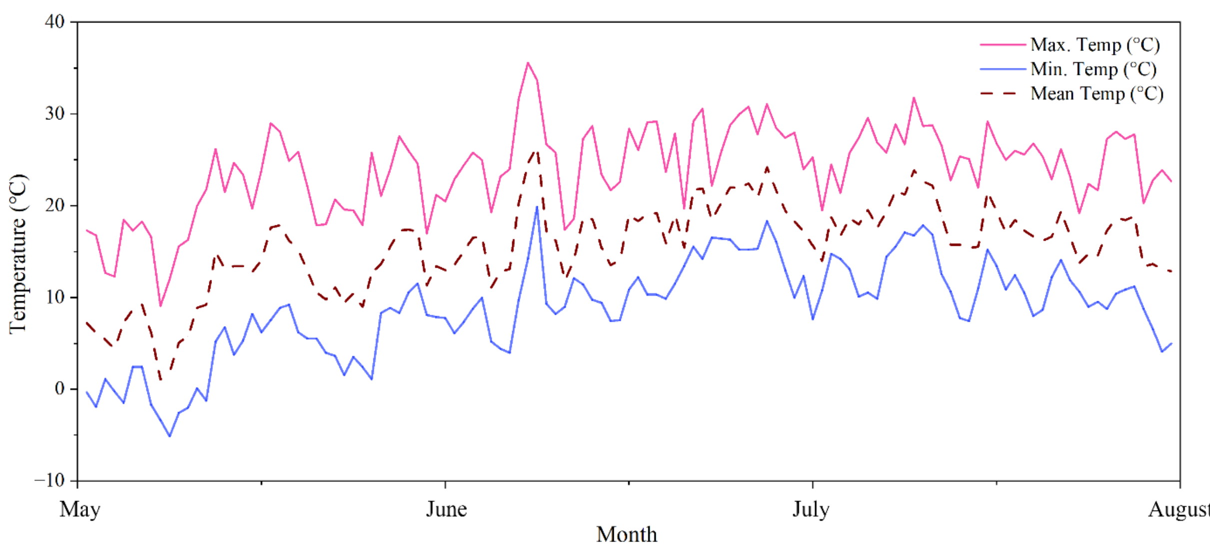


Figure 43 - Monthly temperature change in 2024, in Fredericton, New Brunswick (daily range of temperature (grey bar); 24-hour highs (red sticks), and lows (blue) (*Source: https://climate.weather.gc.ca/).*

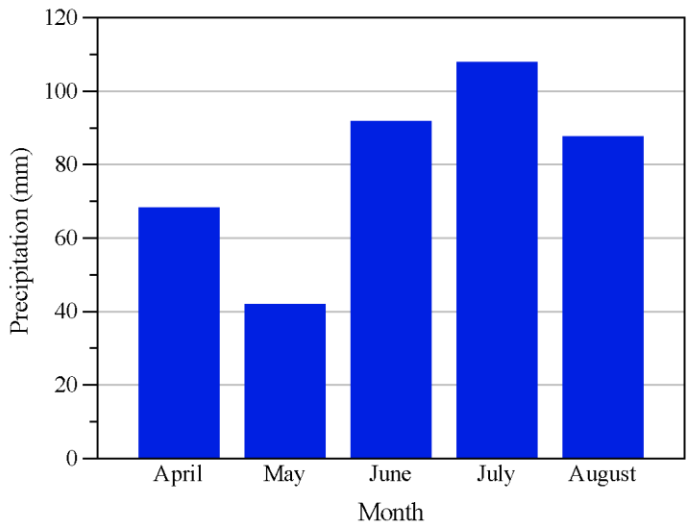


Figure 44 - Monthly precipitation from April to August in 2024 in Fredericton, New Brunswick (*Source: https://fredericton.weatherstats.ca/charts/precipitation-monthly.html*).

4.1.3. Results and Discussion

4.1.3.1. Thermal Cycling Weathering Test

Figure 45 summarizes the dimensional change of aspen and S-P-F siding specimens after 30 cycles. Throughout the Freeze-Soak-Thaw cycle treatment, the specimens experienced dimensional changes, particularly those specimens along the edges. After each cycle, the deformations on the left and right sides of the specimens were measured as the distance between the specimen edges and the frame, using a caliper for measurement.

After 30 cycles, unfinished specimens deformed more than finished ones. The right-side unfinished aspen showed the largest deformation and the left exhibited gentle deformation, with both finished and unfinished groups exhibiting similar trends. Finished aspen showed the smallest average deformation. Significant dimensional changes were observed after cycle 12, with the right side exhibiting greater deformation than the left. Unfinished S-P-F showed the largest increase over three cycles.

The test results indicated that the “Freeze-Soak-Thaw” cycles affect the dimensional stability, varying with wood types and surface finishing protection. Finished aspen exhibited less deformation than S-P-F after the 30-cycle surface treatment. Compared to S-P-F, aspen demonstrated greater dimensional stability when exposed to moisture, heat, and freeze variations.

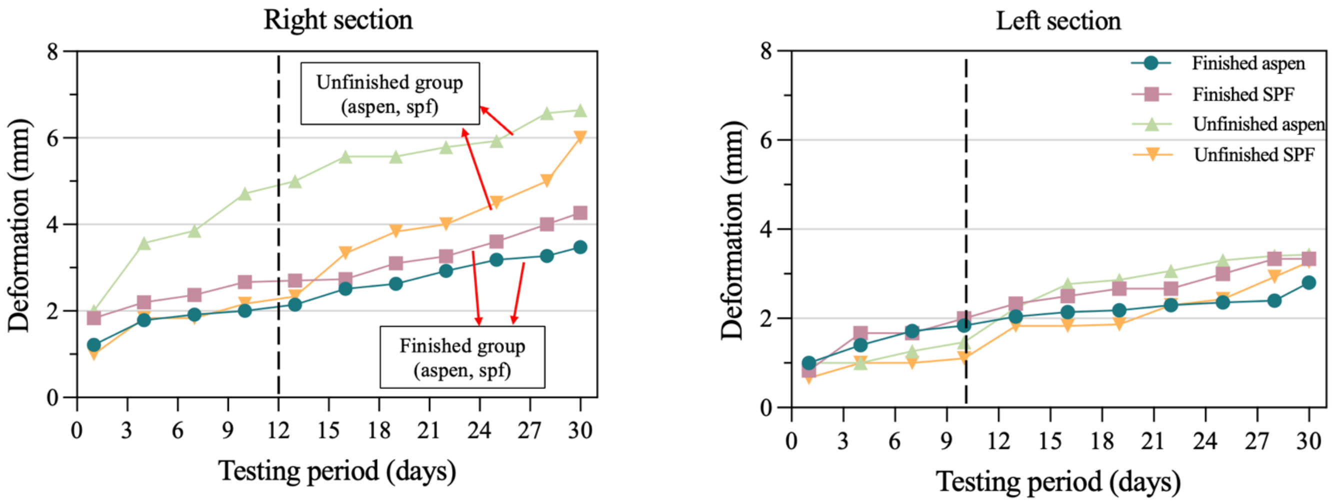


Figure 45 - Change in deformation over time on the right and left sides of the siding specimens during the thermal cycling weathering treatment.

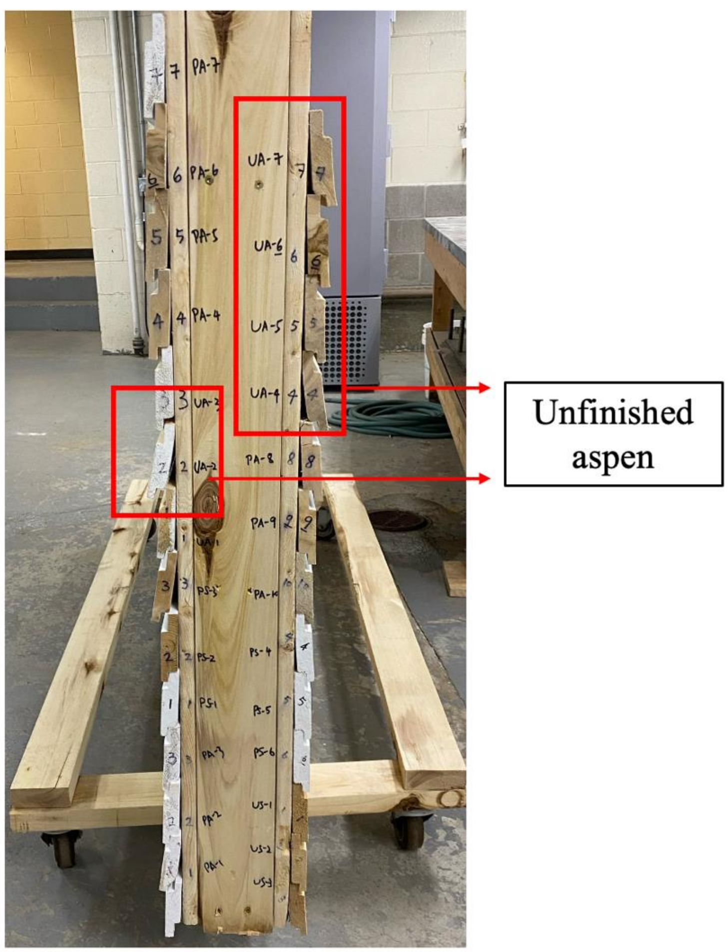
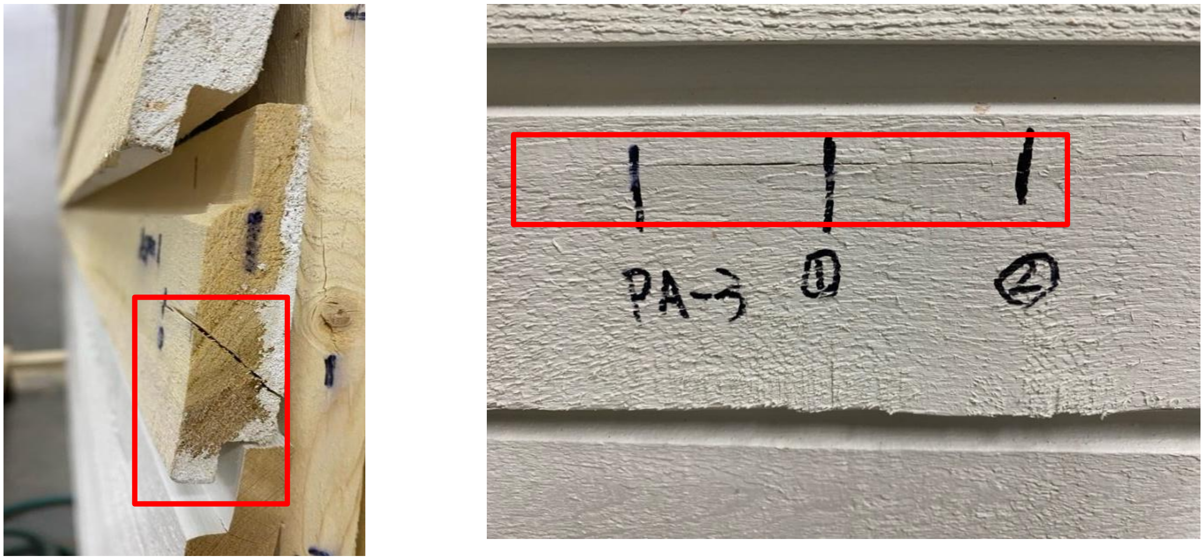


Figure 46 - The change in deformation of the siding specimens on the right side.



a. b.

Figure 47 - Defects on the surface and sides of the siding specimens after testing (a. split in the end of unfinished aspen, b. surface crack in finished aspen).

4.1.3.2. Accelerated Weathering Test

Figure 49 presents the colour changes on the aspen and S-P-F surfaces, with and without finishing, over the weathering exposure. As weathering duration increased, the colour variation became more pronounced in both aspen and S-P-F specimens (Fig. 49).

The overall colour change (ΔE) in aspen was lower than that in S-P-F. For finished aspen siding, the average ΔE increased from 1.2 to 9.9 over the first 1000 hours, representing an 87.9 % change. Between 1000 and 1500 hours, ΔE remained relatively stable, followed by a further 40 % increase from 1500 to 2000 hours.

In contrast, S-P-F exhibited a continuous increase in ΔE throughout 0 to 2000-hour entire exposure period, rising from 1.3 to 14.4, with a total change of 91.0 %. At each time point, S-P-F showed greater colour change than aspen, indicating lower colour stability under the same conditions.

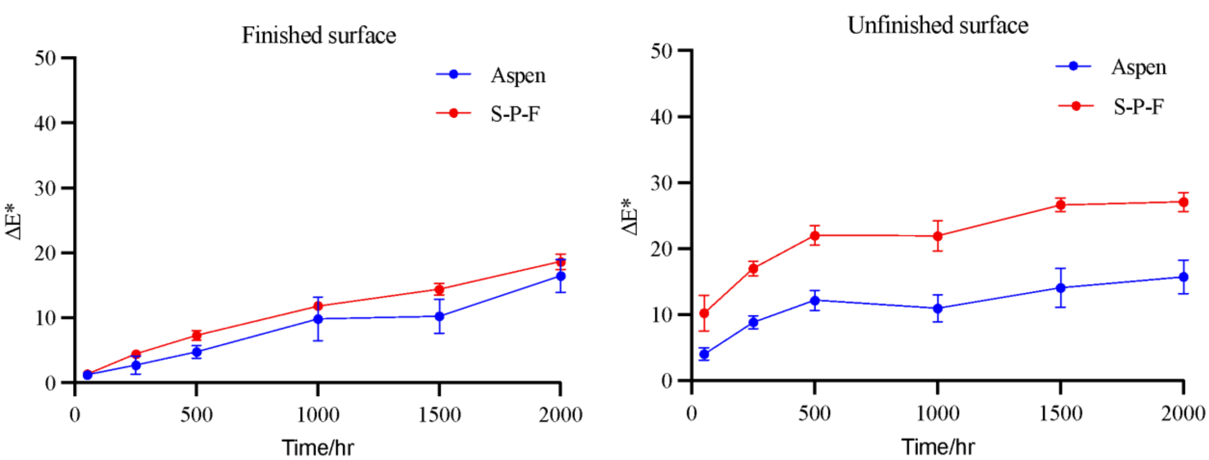


Figure 48 - Variation in ΔE* Over Weathering Exposure.

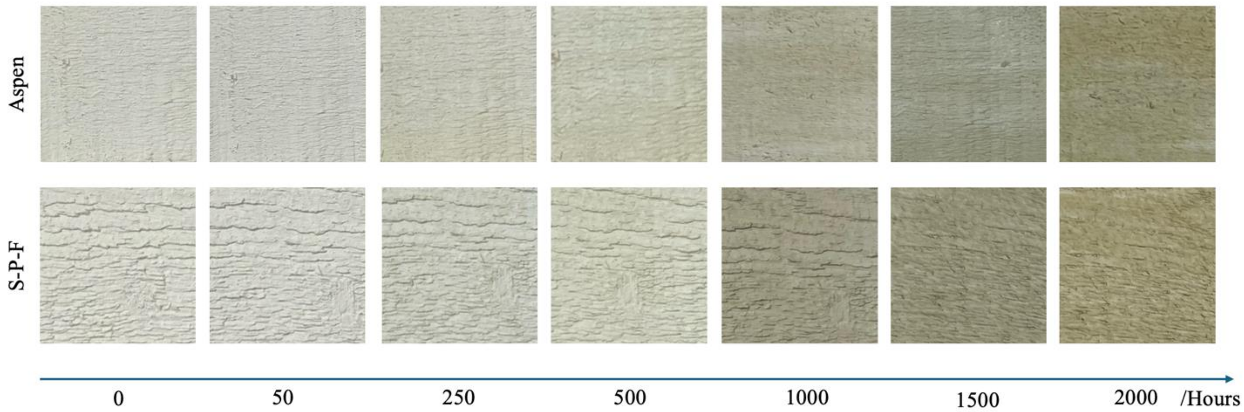


Figure 49 - The colour changes between groups during the weathering testing.

Another notable observation is that after 1000 hours of treatment, the specimens without finishing protection exhibited varying degrees of fibrillation (Figure 50). This effect was particularly pronounced in aspen, where localized areas of decay also developed a yellowish discoloration.

Figure 50 - Surface fibrillation after treatment in the aspen (left) and S-P-F (right) specimens.

In summary, both finished aspen and S-P-F siding showed similar colour change trends during the accelerated weathering test. Additionally, aspen exhibited greater colour stability, even in those specimens without finishing protection. These results suggest a great potential for using aspen to produce exterior sidings.

4.1.3.3. Short-term Weathering

The test site received about 5.2 kWh/m²/day of direct solar radiation, indicating moderate UV exposure, which could result in surface microbial activity and colour changes during testing.

Figure 51 illustrates the surface colour changes in the specimens before and after weathering. The surface finishing significantly influenced the siding specimens. Table 6 quantifies the colour change in the specimens examined over 18 weeks. It can be found that the finished aspen siding specimens showed minimal colour change after 18-week natural outdoor weathering, which was similar to S-P-F. The lower variability in finished specimens suggested improved color stability, indicating that surface finishing effectively preserved color during outdoor exposure. Meanwhile, unfinished aspen demonstrated greater resistance to colour change, maintaining its original appearance in the first 12-week treatment, whereas S-P-F exhibited earlier discoloration. These findings suggest that aspen had potential for outdoor siding applications.

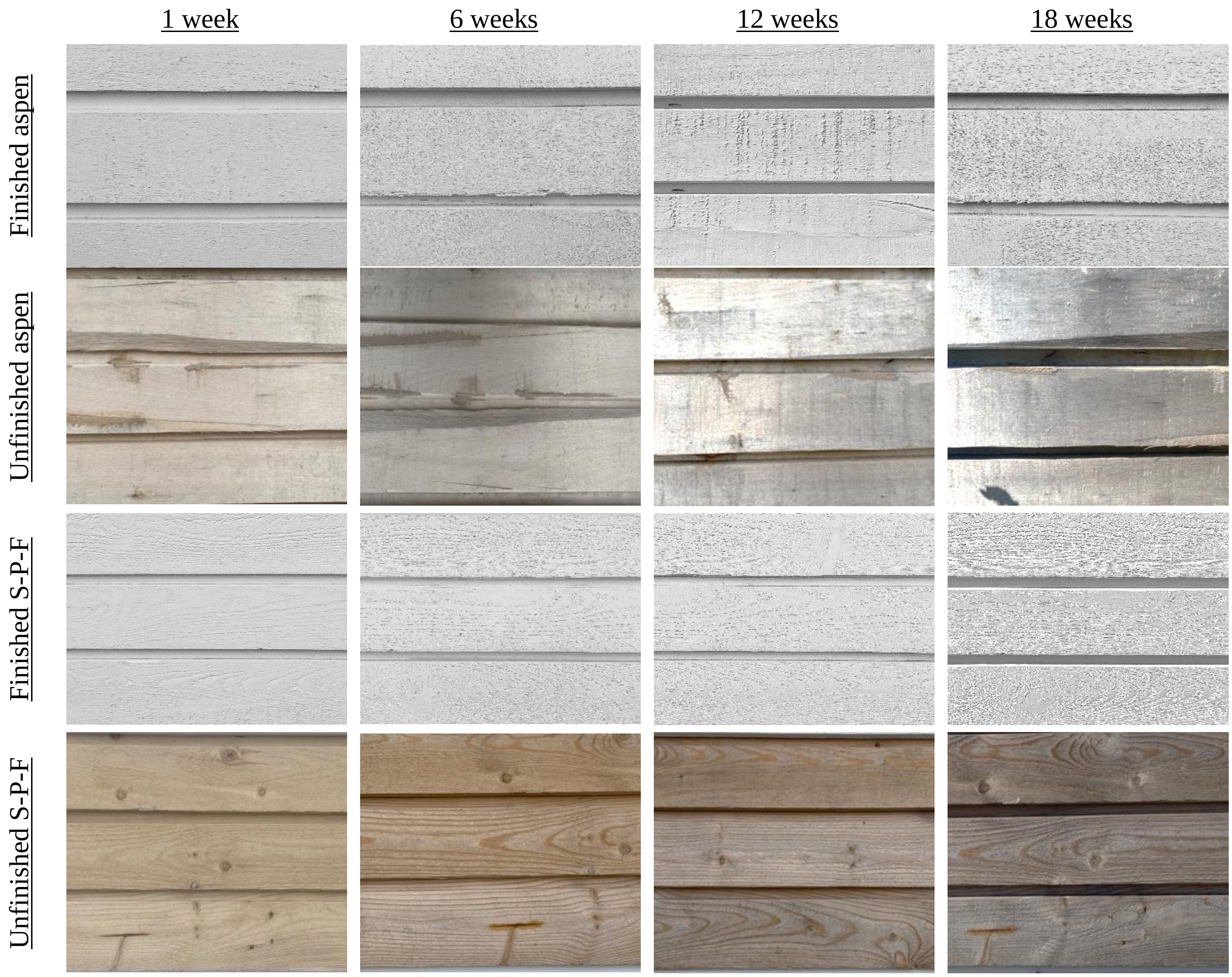
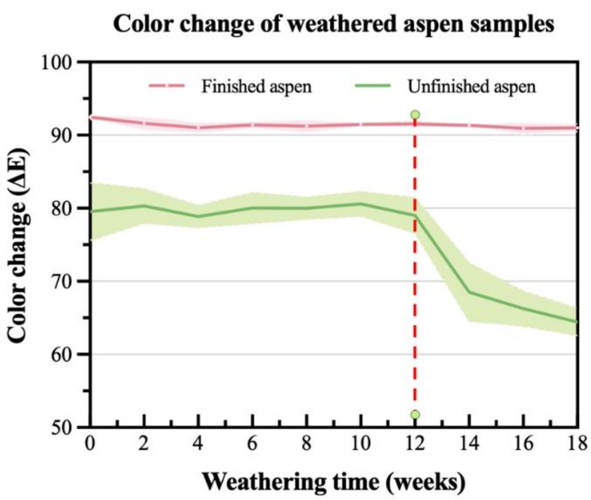


Figure 51 - The change in colour on the surface of the siding specimens over 18-week treatment.

Table 6 - Summary of the colour changes of the siding specimens after 6-, 12-, and 18-week treatment.

Wood Species	Surface Methods	Colour Parameters											
		6 weeks				12 weeks				18 weeks			
		ΔL	Δa	Δb	ΔE	ΔL	Δa	Δb	ΔE	ΔL	Δa	Δb	ΔE
Aspen	Finished	-1.1 (0.7)	0.1 (0.1)	0.4 (0.2)	-1.1 (0.7)	-1.1 (0.4)	0.1 (0.1)	0.3 (0.1)	-1.1 (0.4)	-1.5 (0.8)	0.1 (0.1)	0.5 (0.2)	-1.4 (0.8)
	Unfinished	0.9 (5.2)	-0.7 (1.4)	-1.3 (3.0)	0.5 (4.5)	-9.2 (5.7)	-2.3 (1.5)	-9.3 (3.0)	-11.0 (5.5)	-12.9 (5.0)	-3.0 (1.8)	-13.5 (3.7)	-15.1 (4.4)
S-P-F	Finished	-0.9 (0.8)	0.1 (0.1)	0.2 (0.2)	-0.9 (0.7)	-1.2 (0.8)	0.2 (0.1)	0.3 (0.4)	-1.2 (0.8)	-1.5 (0.5)	0.2 (0.1)	0.3 (0.3)	-1.5 (0.5)
	Unfinished	-16.6 (4.3)	3.9 (1.1)	0.1 (3.1)	-11.7 (1.5)	-16.8 (3.4)	-0.6 (1.8)	-13.3 (4.5)	-19.9 (2.6)	-17.4 (4.3)	-1.9 (1.6)	-18.0 (2.9)	-21.4 (3.7)

Note: Numbers in parentheses are standard deviations.



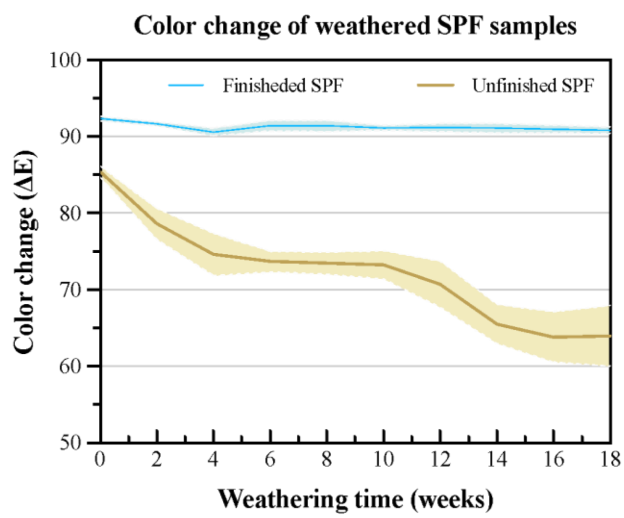


Figure 52 - Weathering time-dependent curves of average colour changes (ΔE). The red dashed line indicates the point at which aspen began to exhibit noticeable changes at 12 weeks.

4.1.3.4. Yield Analysis of Exterior Use Products

Similar to the production of flooring and moulding products, Cape Cod Siding applies an “Up-grade” method to ensure the surface quality of lumber before manufacturing. This process involves filling knots, worm holes, and pitch pockets with epoxy resin, which minimizes MC variation and ensures uniform painting. This method helps achieve a high product yield of 90-95%. Aspen lumber graded as No.2 & Better is similarly upgraded, with only minimal losses due to edge cracking, resulting in a yield of approximately 96.0%. The overall yield value for exterior siding products was 49.2%. Due to variations in production requirements across manufacturers, siding product yields may fluctuate. In this study, the overall

yield of exterior aspen siding manufactured by Cape Cod is 49.2%.

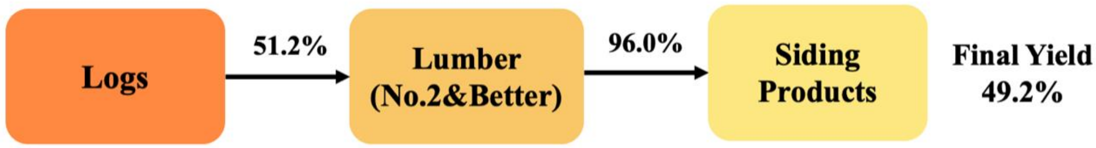


Figure 53 Estimation of the yield in the production of aspen siding from logs to siding products.

4.2. Trembling Aspen Treated Lumber

4.2.1. Materials and Manufacturing

Six (6) pieces of 5-ft-long, 2x4 aspen and six S-P-F lumber pieces of the same size and length were randomly selected and sent to a local treatment company, Marwood Ltd., Tracyville, New Brunswick. for pressure treatment. Prior to shipping, both aspen and S-P-F specimens were conditioned at 20°C and 65% RH for two weeks until they reached approximately 12 % moisture content (MC).

4.2.2. Testing

4.2.2.1. Penetration Depth of Preservative

Marwood applied the water-based preservative Alkaline Copper Quat (ACQ)-D to aspen and S-P-F lumber, containing 66.7% copper oxide and 33.3% quat, using a vacuum-pressure process. Excess solution was wiped off, and the specimens were then dried in a conditioning chamber with fans until reaching approximately 12% MC. Each specimen was sliced into three sections, and five random measurement points were selected from each slice (15 data points per species). Depth of penetration was measured using a microscope (Model: OMAX).

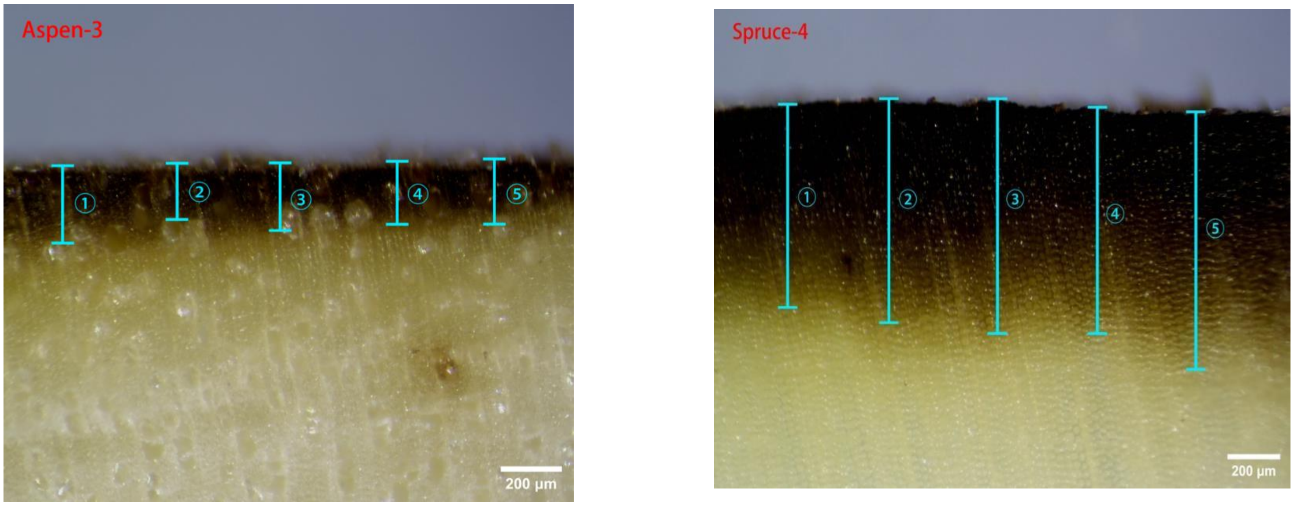
4.2.3. Results and Discussion

4.2.3.1. Penetration Depth of Preservative

Table 7 presents the average penetration depth of treated aspen and S-P-F specimens. It can be found that that the average penetration depth of aspen is 311.53 µm, which is 62.5% lower than that of S-P-F specimens, suggesting a poor penetration of chemicals in aspen. However, according to the CSA O80 "Wood preservation" (CSA 2021), both ACQ treated aspen and S-P-F specimens did not pass the minimum penetration requirement of 5 mm. Cross-sectional analysis revealed that ACQ solution penetrated the interior of aspen specimens through surface defects, resulting in localized regions with greater penetration depth than surrounding, defect-free areas. These defects primarily included insect holes, decay, and knots (Figure 55).

Table 7 -Preservative penetration depths of two wood species examined.

Wood species	Preservative penetration (µm)	
	Mean	SD
Aspen	311.53	80.96
S-P-F	830.53	291.35



a. b.

Figure 54 - Depth measurement of preservative penetration depth in aspen (a) and S-P-F (b).

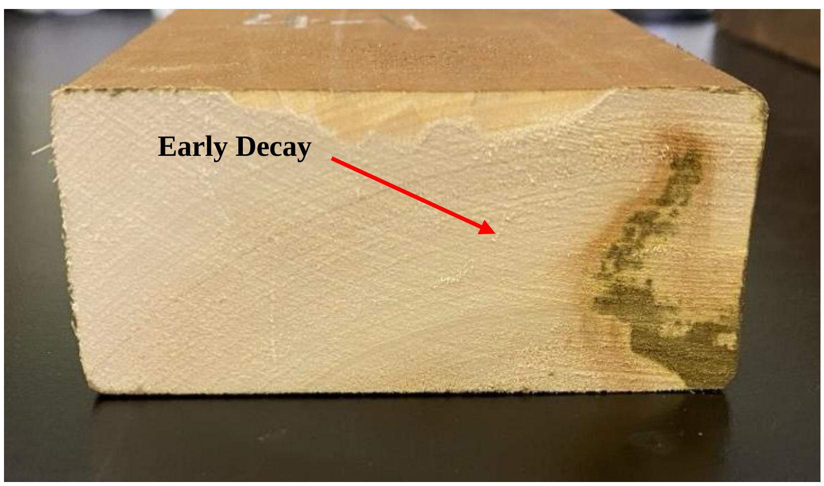


Figure 55- Preservative penetration through surface defects in aspen.

5 GENERAL CONCLUSIONS

Based on the test results and the preceding discussion, the following conclusions can be drawn:

► For trembling aspen wood:

- Aspen wood demonstrated average shrinkage of 6.1 %, 5.2 %, and 0.1 % in tangential, radial, and longitudinal directions, respectively. The small difference in shrinkage between tangential and radial directions suggested a good dimensional stability of aspen lumber products.
- Sanded aspen, with an average roughness of 8.33 µm compared to 4.40 µm for planed surfaces, exhibited an adhesion strength of 3.80 MPa, 7.6 % higher than that of planed surfaces.
- Aspen wood exhibited a Brinell hardness of 22.51 MPa and screw withdrawal resistance of 20.90 MPa in the radial direction, 30.0 % and 5.6 % higher than in the tangential direction.

► For trembling aspen flooring and moulding:

- Aspen flooring had a Brinell hardness of 13.47 MPa and an oven-dry SG of 0.42, while silver maple flooring had a Brinell hardness of 33.44 MPa and an oven-dry SG of 0.70.
- Aspen moulding had an average screw withdrawal resistance of 23.42 MPa, 13.0 % lower than yellow poplar and 17.6 % higher than eastern white pine. Aspen's SG averaged 0.42, 12.5 % lower than yellow poplar and 5.0 % higher than eastern white pine.
- The yield values for aspen flooring and moulding were 35.2 % and 25.4 %, respectively, in this study from logs to kiln-dried lumber.

► For trembling aspen exterior siding:

- The test of "Freeze-Soak-Thaw" cycles caused dimensional changes, with largest change appearing in unfinished aspen siding, also leading to the formation of siding surface checks and end splits.
- Surface finishing assisted to preserve color in aspen, with finished specimens showing the best performance.
- Aspen and S-P-F siding exhibited similar color change trends during accelerated weathering, but aspen demonstrated better color stability.
- The overall yield for aspen siding products in this study was about 49.2 %.

► For preservative-treated trembling aspen lumber:

- Aspen lumber was more difficult to treat than S-P-F, with the preservative solution tending to penetrate from the surface defects, resulting in uneven absorption.

6 FUTURE WORK AND RECOMMENDATIONS

This study presents comprehensive testing data and analytical results through the evaluation of aspen wood and the non-structural wood products made for it. The findings provide valuable insights and serve as a reliable reference for producing trembling aspen wood in Alberta. Further research should focus on optimizing processing and improving product performance to fully explore aspen's potential. The future recommendations can be made as follows:

1) **Surface Dressing:** An optimal surface dressing approach shall be developed when using aspen to produce siding.

2) **Weathering Tests:** Extended weathering tests shall be conducted, including both natural and accelerating treatment, with an aim to provide the warranty information of siding.

3) **Yield Studies:** Although this project has provided yield information for each product studied, the results were based on data from one sawmill with one log supply only. More thorough yield studies shall be performed for each production line that fully considers the range of log quality to better understand the economic feasibility of producing non-structural products using trembling aspen lumber.

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