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ORIGINAL ARTICLE

Evaluation of the durability of the exterior siding products made with trembling aspen lumber in terms of colour change

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Abstract: Trembling aspen (*Populus tremuloides*) is a fast-growing and widely distributed species in Canada, but its uses in non-structural wood products are limited. This study was aimed at evaluating the feasibility of using aspen lumber for producing wood siding products and their durability in terms of colour change (ΔE). Both short-term natural exposure and artificial accelerated weathering tests were conducted on the aspen wood sidings produced and pressure-treated on a production line. The spruce-pine-fir (S-P-F) sidings were used as control. It was found that (1) both short-term natural and artificial accelerated weathering tests resulted in an increase in average ΔE of the siding specimens, exhibiting surface greying and darkening. (2) Finished trembling aspen siding specimens consistently exhibited greater colour stability than finished S-P-F ones. (3) Both finished trembling aspen and S-P-F siding specimens had smaller ΔE values than unfinished ones, suggesting the finishing employed in this study effectively protected surface colour.

Keywords: Trembling aspen, exterior siding, weathering, colour change

1 Introduction

Trembling aspen (*Populus tremuloides*), a key species within the *Populus* group, constitutes a major deciduous resource in Canada, with its cultivation covering approximately 80% of Alberta's deciduous forests. It accounts for more than 800 million m^3 of standing timber [1]. Trembling aspen is a fast-growing species, known for its low density and soft texture, making it currently widely used in traditional industries such as papermaking and oriented strand board (OSB) production However, it is rarely used for exterior-use products due to its susceptibility to decay, moisture absorption, and unknown colour changes when exposed to environmental conditions [2-3]. Its limited durability, coupled with issues like dimensional instability and surface defects, renders it less suitable for long-term outdoor use, although proper treatment and finishes may enhance its performance in such applications [4]. Wood species like western red cedar (*Thuja plicata*), redwood (*Sequoia sempervirens*), and chemically treated pine (*Pinus* spp.), are commonly employed for exterior purposes, including siding, decking, and fencing, due to their inherent durability, moisture resistance, and ability to endure various environmental conditions [5-6]. However, whether trembling aspen can be employed to produce wood products for exterior uses remains underexplored.

Wood siding is a protective exterior covering that enhances both the appearance and durability of buildings. It comes in various forms, such as clapboards, shingles, shakes, and panels, selected based on architectural style, climate, and maintenance needs. However, wood is susceptible to weathering, a

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complex process that alters its molecular structure and leads to surface degradation [7]. Environmental factors, particularly solar radiation, play an essential role in initiating wood surface degradation. Short-wavelength ultraviolet (UV) light, with higher photon energy, penetrates deeper into wood's polymeric structure and weakens the chemical bonds in the cell walls [8]. The initial signs of weathering include colour changes, followed by surface checking and other defects. Discolouration, often a yellowing effect, indicates chemical alterations within the wood cell walls, particularly involving lignin and hemicelluloses. Photochemical reactions degrade lignin, which is subsequently washed away by rain, leaving the more UV-resistant cellulose intact, contributing to the wood's greyish appearance [9-10]. Trembling aspen, for example, exhibits moderate weathering resistance, turning a light grey with a moderate sheen, and developing small, unobtrusive checks over time [11]. Spruce-pine-fir (S-P-F) lumber is widely applied in siding production across Canada, but its limited natural durability, susceptibility to surface checking, and weather-induced discolouration constrain its use in exterior siding without preservative treatments [6]. In contrast, trembling aspen shows moderate weathering resistance, developing a light grey surface with minimal checking and relatively stable roughness under exposure [11]. Given that aspen had similar lignin degradation under UV exposure to other hardwood species, it may respond well to protective coatings [9-10, 12]. These findings suggest that, with proper surface treatment, trembling aspen could serve as a viable and sustainable alternative to S-P-F for exterior siding applications.

Accelerated weathering is commonly used for prediction, understanding, and reproducibility in wood protection research. It accelerates natural weathering processes, allowing for rapid evaluation of protective treatments [13]. Accelerated weathering protocols typically involve variables such as UV radiation, cyclic temperature changes, moisture through spraying, and controlled humidity. For example, Kropat et al. [13] applied these conditions in their QUV-based testing of European beech (*Fagus sylvatica* L.) and Scots pine (*Pinus sylvestris* L.) to simulate natural degradation processes. Their study simulated natural weathering through UV radiation, temperature cycling, and moisture exposure (condensation and water spray). After 500 hours, beech exhibited a colour change (ΔE) of 17.2, significantly higher than the 11.8 observed for pine, demonstrating that beech was more susceptible to UV-induced degradation. Several studies investigated the relationship between artificial accelerated and natural weathering and reported good agreement in estimating conversion factors [14-16]. Feist and Mraz [16] observed a strong correlation in erosion rates for western red cedar (*Thuja plicata*), indicating that one year of natural exposure in Wisconsin, USA, corresponded to approximately 6-9 weeks of accelerated weathering in the early stages, and around 5 weeks in the later stages. Deppe and Schmidt [15] developed a Xenotest protocol for evaluating wood-based composites and reported that 12 weeks of accelerated weathering produced dimensional changes equivalent to those observed after three years of natural exposure in Germany. Similarly, Almeida et al. [14] evaluated the mechanical properties of both softwood and five tropical hardwoods in Brazil and found that 12 hours of accelerated weathering was comparable to 6.22 days of natural weathering. Based on the insights derived from these studies, it can be reasonably inferred that the conversion ratio between accelerated and natural weathering treatments varies significantly, ranging from approximately 4 to 20, with an average value of 12. This suggests a relatively reliable estimate that one month of accelerated weathering treatment could correspond to the effects of approximately one year of natural exposure.

To explore the feasibility of trembling aspen for producing wood siding products, this study evaluated its durability in terms of surface colour change following exposure to both short-term natural weathering and artificial accelerated treatments.

2 Materials and Methods

2.1 Materials

Thirty pieces of trembling aspen lumber, each of which had dimensions of 38 mm × 89 mm × 2,590 mm (thickness × width × length), were randomly selected from a sawmill located in La Crete, Alberta. These lumber pieces were then shipped to Cape Cod Finished Wood Siding Ltd. in Bedford, Nova Scotia, where they were processed into siding specimens in the company's production line. 30 finished aspen and 10 S-P-F pieces were prepared, each measuring 20.3 mm (0.8 in.) in thickness, 35.6

mm (1.4 in.) in width, and 2,590 mm (8.5 ft.) in length. All siding specimens featured a "channel" profile (**Fig. 1**). For comparative purposes, both finished and unfinished specimens of trembling aspen and S-P-F were included in this study. Each test included an equal number of finished and unfinished specimens for consistency.

Fig. 1. Finished exterior siding specimens made of trembling aspen (left) and S-P-F (right).

Table 1. Summary of the dimensions and quantities of siding products manufactured and specimens for weathering testing.

Product/Testing	Species	Dimension						Quantity (Pcs.)
		Length		Width		Thickness		
		foot	mm	inch	mm	inch	mm	
Exterior siding	Trembling aspen	8.5	2,590	1.4	35.6	0.8	20.3	40
	S-P-F	8.5	2,590	1.4	35.6	0.8	20.3	10
Short-term weathering test	Trembling aspen	6	1,830	1.4	35.6	0.8	20.3	6
	S-P-F	6	1,830	1.4	35.6	0.8	20.3	6
Accelerated weathering test	Trembling aspen	0.5	140	1.4	35.6	0.8	20.3	10
	S-P-F	0.5	140	1.4	35.6	0.8	20.3	10

2.2 Methods

2.2.1 Short-term Natural Weathering Test

a. b. c.

Fig. 2. Short-term weathering: (a) testing setup sketch, (b) measurement of surface colour, and (c) colourimeter used).

In this test, specimens were selected and cut from siding products. These specimens were then nailed to a frame and positioned on a rack in the pole yard near to the Wood Science Technology Centre

(WSTC), Fredericton, Canada, following ASTM G7 [17], the wide face of each specimen was oriented southward at a 45-degree inclination (**Fig. 2a**). Specimens were inspected biweekly over four months. Surface colour changes were measured using a colourimeter (Model: BYK-Gardner GmbH Spectro2guide, Germany) and reported as CIELAB *L**, *a**, and *b** values.

The test site is reported to experience 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 1,118 mm, mainly during summer, and monthly average temperatures range from 2 ℃ to 25 ℃ (**Figs. 3 and 4**) [18-19].

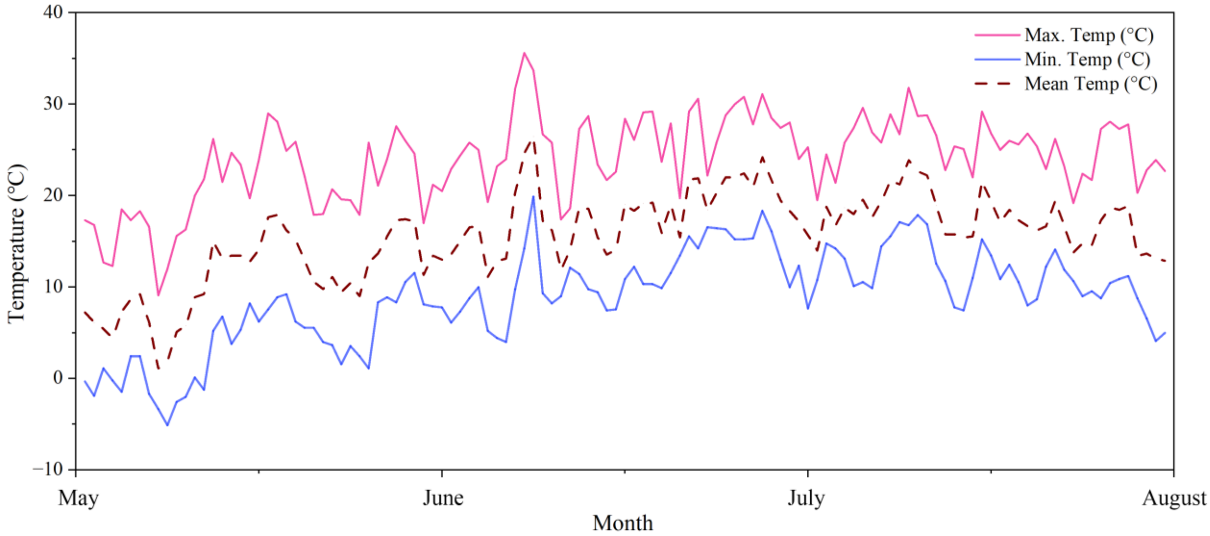

Fig. 3. Temperature change from May to August in 2024 in Fredericton, New Brunswick, Canada [18].

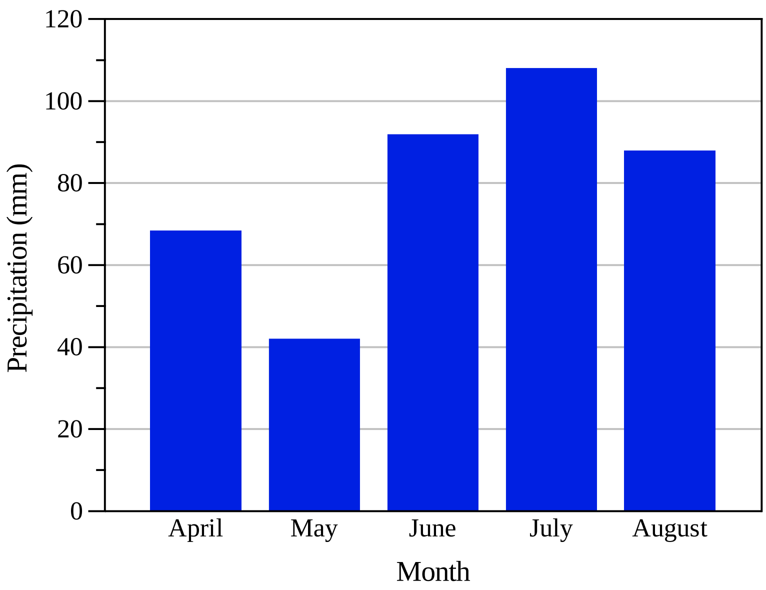

Fig. 4. Monthly precipitation from May to August in 2024 in Fredericton, New Brunswick, Canada [19].

2.2.2 Artificial Accelerated Weathering Test

The durability of trembling aspen siding was examined through artificial accelerated weathering, designed to replicate outdoor exposure, and S-P-F was included as a comparative benchmark. The test followed the treatment of cycle 1 stipulated in ASTM G155 [20]. The specimens were mounted and treated in a weather-o-meter (Model: Atlas Ci4400), **Fig. 5.**

Fig. 6 illustrates a complete test cycle based on ASTM G155. A complete cycle of the accelerated weathering procedure spanned 120 minutes, consisting of 102 minutes under light exposure and 18 minutes of light combined with water spraying. The full test consisted of 1,000 cycles, totalling 2,000 hours, with exposure conditions detailed in **Table 2**. To monitor and assess changes throughout the testing process, the specimens were periodically taken out for measurements of colour, mass, and dimensions at intervals of 50, 250, 500, 1,000, and 1,500 hours. To ensure the accuracy of the experimental results, the equipment was calibrated every 200 hours during the testing process. After exposure, all the specimens were evaluated based on changes in colour and the occurrence of checks in wood. The colour was recorded using the colourimeter.

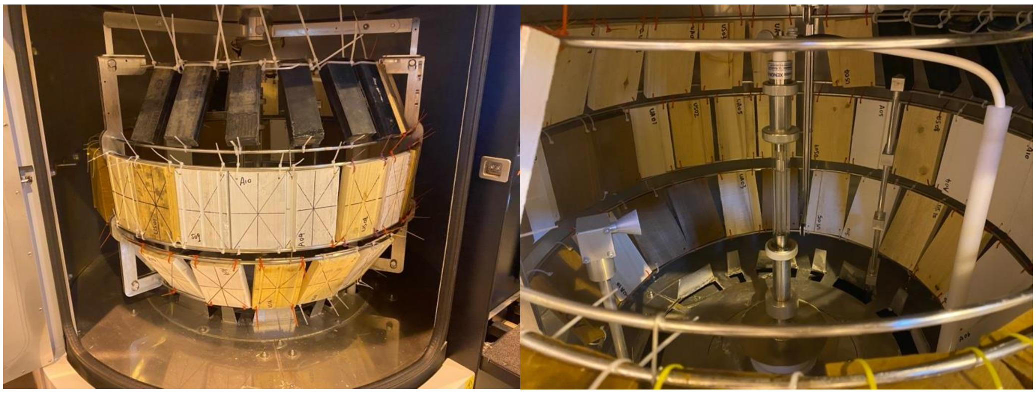

Fig. 5. Artificial weathering test of siding specimens in a weather-o-meter.

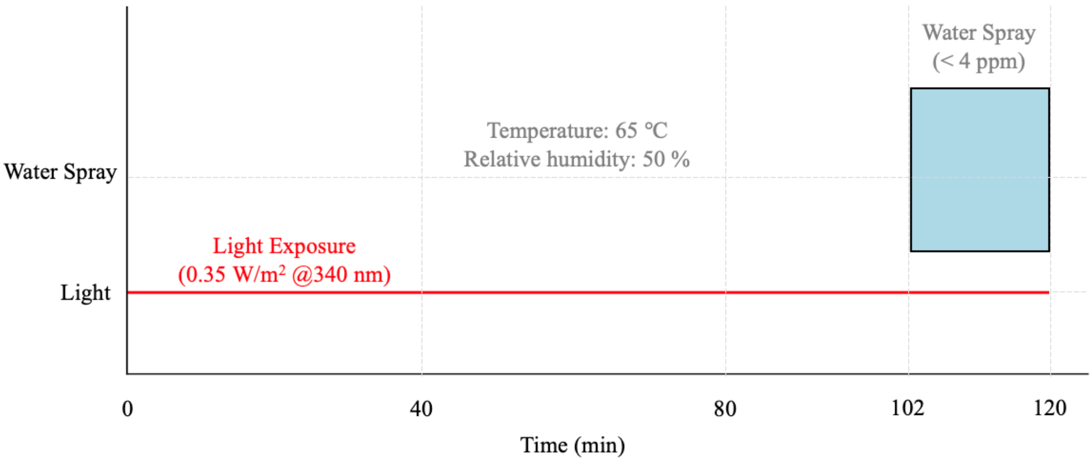

Fig. 6. Schematic of a complete single weathering treatment cycle in this study.

Table 2. Summary of exposure conditions for the accelerated weathering procedure.

Phase	Irradiance and Wavelength	Exposure Treatment	Temperature	Relative humidity (RH)	Water Purity
1	0.35 W/m^2 @340 nm	102-min light	65 ℃	50 %	-
2		18-min water spray and light	-	-	< 4 ppm

2.2.3 Calculations

In this study, the CIELAB colour space was used to assess colour change during the testing process, which defines colour using three coordinate axes [21]: L^* indicates brightness (white at $+L^*$, black at $-L^*$), a^* measures chromaticity along the red-green spectrum ($+a^*$ for red, $-a^*$ for green), and b^* reflects the yellow-blue axis ($+b^*$ for yellow, $-b^*$ for blue). The colour difference (ΔE) before and after the weathering periods, which can be calculated using Eq. 1, was used to evaluate the colour changes resulting from the weathering test [22].

$$\Delta E = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2} \quad (1)$$

Where, L_1, a_1, and b_1 represent the initial colour coordinates, while L_2, a_2, and b_2 denote the corresponding values measured after weathering.

3 Results and Discussion

3.1 Short-term Natural Weathering Test

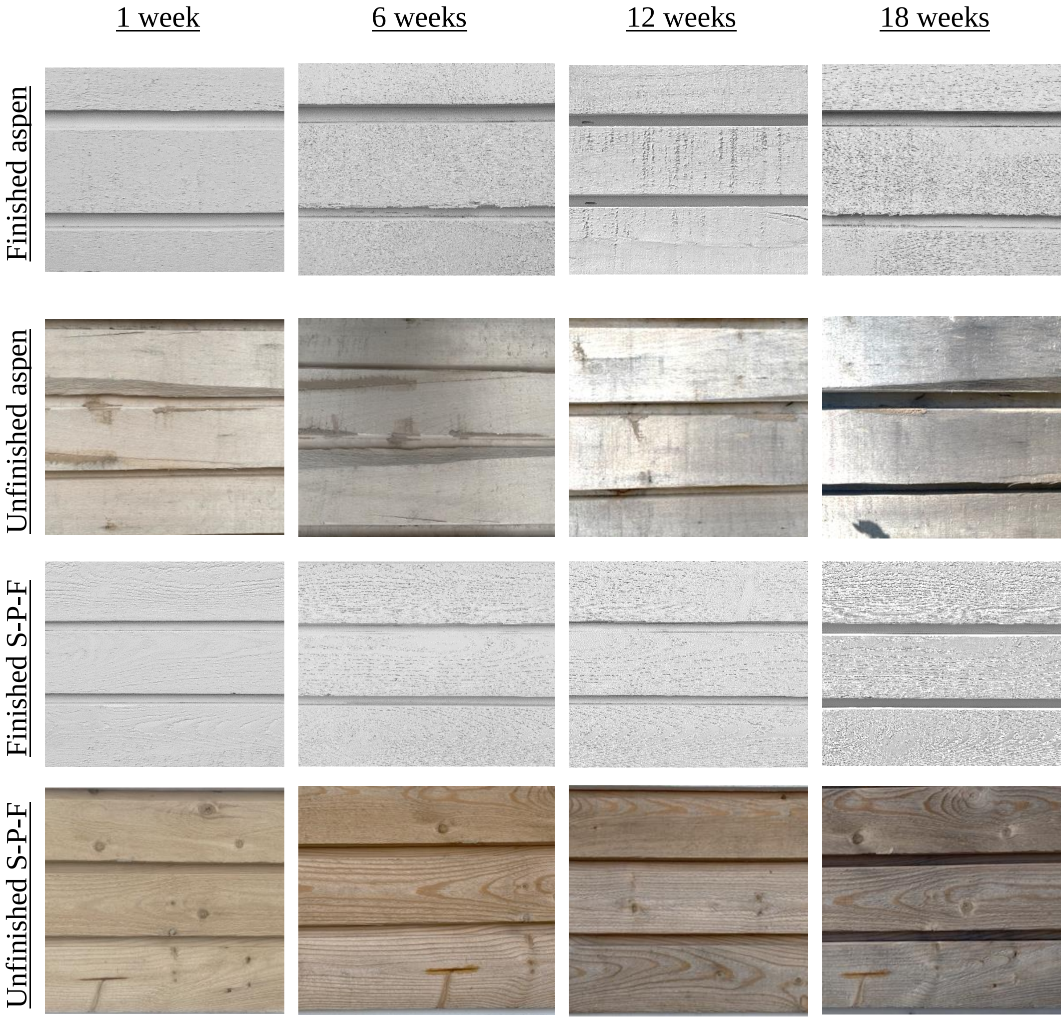

Fig. 7. Surface colour changes of wood siding specimens over the 18-week weathering treatment.

The test site received about 5.2 $kWh/m^2/day$ of direct solar radiation, indicating moderate UV exposure, which could result in surface microbial activity and colour changes during testing [18]. **Fig. 7** shows the colour changes on the surface of siding specimens over 18 weeks of exposure, beginning from the first week. The effects of natural weathering on trembling aspen and S-P-F siding specimens reveal distinct differences influenced by surface finishing. Over 18 weeks of exposure, finished aspen and S-P-F maintained a relatively consistent light grey colour, with their colour changes being modest. Some fading of the finish was noticeable in both siding specimens, particularly in the trembling aspen specimens. This could be attributed to the fuzzy grain existing in aspen wood, which became visible as the coating gradually thinned under environmental exposure. In contrast, the unfinished specimens showed more pronounced changes, with the surfaces of both trembling aspen and S-P-F turning grey and partially blackened by week 18. This indicated the critical protective role of surface coatings in minimizing UV-induced discolouration and moisture effects. Similar results were reported by Cogulet et al. [23], who found that applying coatings on yellow birch (*Betula alleghaniensis*) and sugar maple (*Acer saccharum*) could reduce UV-related discolouration and moisture absorption by 30-50%. In their study, the coated samples had ΔE values up to 50% lower than those of the uncoated controls.

In contrast, unfinished aspen transitioned rapidly from light brown to a uniform grey within 18 weeks, while unfinished S-P-F darkened from light brown to brown-grey with visible weathering effects. A comparable trend was reported by Arpaci et al. [24], who observed that natural weathering led to pronounced discolouration in both trembling aspen and S-P-F. After 12-month exposure, ΔE values surpassed 20, primarily as a result of lignin degradation and moisture effects. Collectively, these studies underscore the vulnerability of unfinished wood to environmental stresses and highlight the effectiveness of coatings in preserving wood aesthetics under the natural weathering condition.

Table 3 lists the L^*, a^*, and b^* values over 6, 12, and 18 weeks. The surface finishing significantly influenced the wood siding specimens examined in this study. In the first week, unfinished aspen exhibited L^*, a^*, and b^* values of 77.0, 4.3, and 19.1. After 18 weeks of outdoor exposure, these values decreased to 64.1, 1.3, and 5.6, representing reductions in lightness was 16.8%, a^* decreased by 69.8%, and b^* decreased by 70.7%, with a shift from yellow colour toward blue colour. The standard deviations (SDs) for L^*, a^*, and b^* dropped from 4.4 to 1.8, 1.4 to 0.4, and 2.8 to 1.2, respectively. As for finished aspen specimens, L^* and a^* values declined by 1.5% and 9.0%, while b^* increased by 20.8%. The SDs for L^*, a^*, and b^* slightly increased, from 0.3 to 0.5, 0.0 to 0.1, and 0.1 to 0.2, respectively.

Table 3. Average surface colour changes of siding specimens after 6, 12, and 18 weeks of exposure.

Wood Species	Surface Method	Colour Parameters											
		6 weeks				12 weeks				18 weeks			
		ΔL	Δa	Δb	ΔE	ΔL	Δa	Δb	ΔE	ΔL	Δa	Δb	ΔE
Trembling 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.

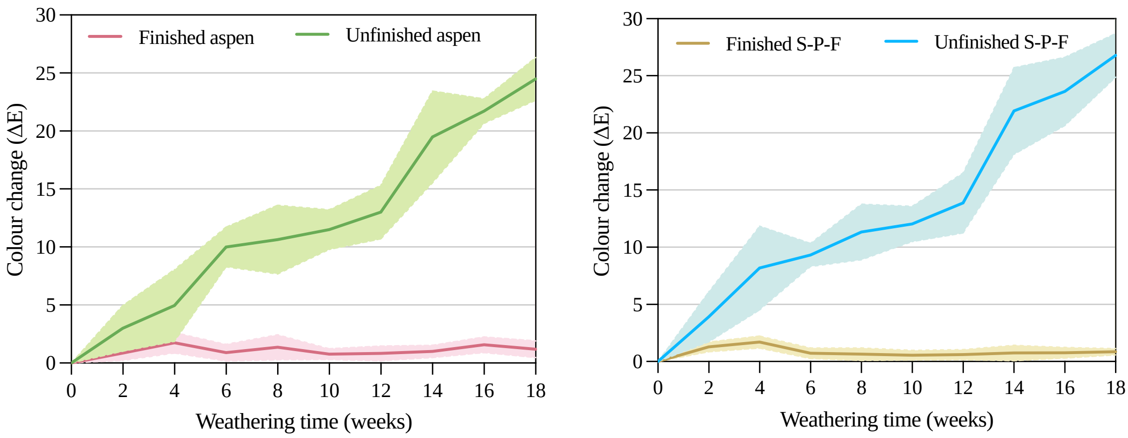

Fig. 8. The time-dependent weathering curves of average colour changes (ΔE) of wood siding specimens: (upper) trembling aspen and (lower) S-P-F.

Fig. 8 illustrates the variation in average colour change (ΔE) for trembling aspen and S-P-F specimens at 6, 12, and 18 weeks of weathering. In both species, finished specimens exhibited the smallest ΔE after 18 weeks, confirming the effectiveness of surface finishing in reducing discolouration. Trembling aspen demonstrated greater average colour stability than S-P-F throughout the test period. At week 18, the average colour change of unfinished S-P-F reached approximately 27.4, which was 3.0 higher than that of unfinished aspen (24.4). Among finished specimens, aspen also showed better performance, with an average colour change of 10.5, which was 1.5 lower than that of finished S-P-F, measured at 12.0.

In addition to limiting overall discolouration, surface finishing improved colour consistency over time. For trembling aspen siding specimens, the average colour change of the unfinished surface was

13.9 higher than that of the finished surface. In the case of S-P-F siding, the unfinished specimens exhibited an average colour change 15.4 higher than the finished ones. These results aligned with the findings of trembling aspen that were exposed to sunlight and moisture leading to visible surface changes in unprotected wood [13]. The reduced variability observed in finished specimens supported the conclusion that surface finishing enhanced colour stability and could help preserve the visual integrity of wood during weathering.

3.2 Artificial Accelerated Weathering Test

Fig. 9 presents the colour changes on the surfaces of trembling aspen and S-P-F siding specimens, with and without finishing, over the weathering exposure. As weathering duration increased, the colour variation became more pronounced in both trembling aspen and S-P-F specimens. The overall ΔE in trembling aspen specimens was lower than that in S-P-F ones. For finished aspen siding, the average ΔE increased from 1.2 to 9.9 over the first 1,000 hours, representing an 87.9% change. Between 1,000 and 1,500 hours, ΔE remained relatively stable, followed by a further 40% increase from 1,500 to 2,000 hours. In contrast, the S-P-F specimens exhibited a continuous increase in ΔE throughout 0 to 2,000-hour entire exposure period, rising from 1.3 to 14.4, with a total change of 91.0%. At each time interval, the S-P-F specimens showed greater colour change than the trembling aspen ones, indicating lower colour stability under the same weathering condition.

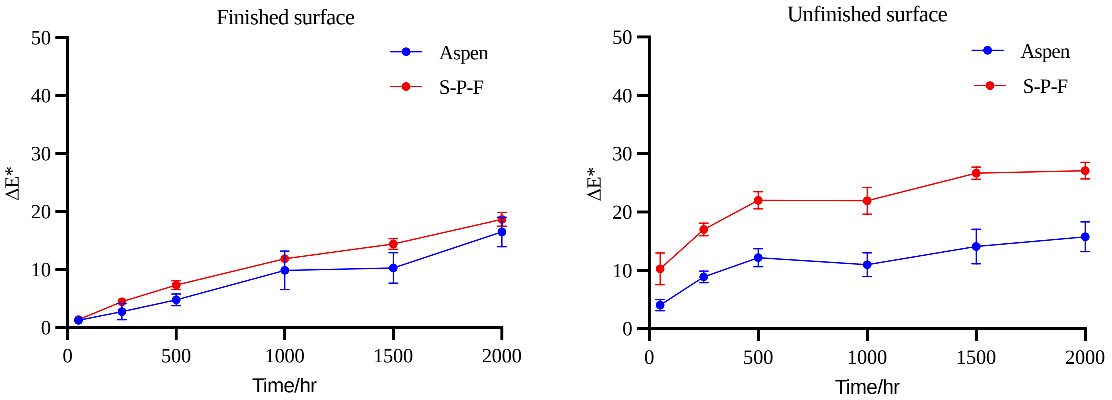

Fig. 9. Variation in ΔE^* over the artificial accelerated weathering treatment.

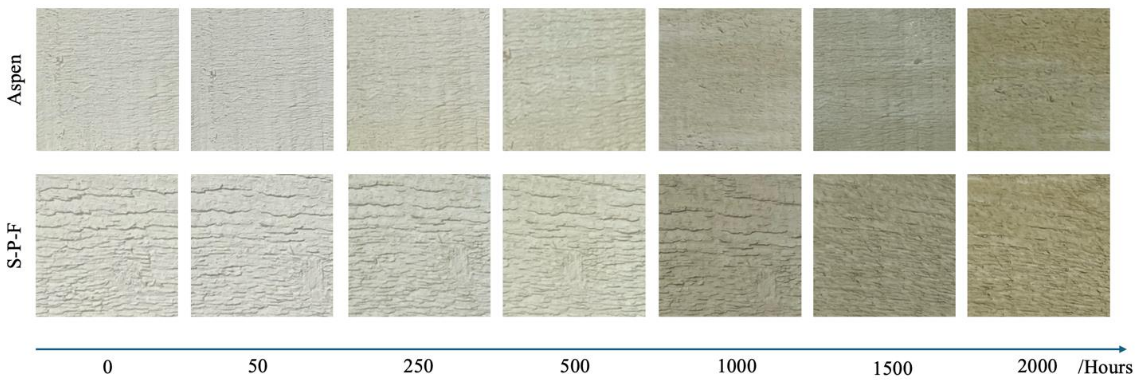

Fig. 10. The colour changes between trembling aspen and S-P-F specimens over weathering.

Based on the visual progression over 0-2,000 hours, both trembling aspen and S-P-F siding specimens exhibited gradual surface darkening under accelerated weathering (**Fig. 10**). While trembling aspen showed a relatively uniform greying with subtle yellowing at later stages, S-P-F specimens demonstrated a more pronounced browning and deeper colour shift by 1,000 hours. Despite similar overall trends of discolouration, S-P-F surfaces appeared to undergo more intense visual degradation than trembling aspen over time. It 2,000 hours of ASTM G155 Cycle 1 testing likely simulates around 2 to 3 years of severe outdoor exposure, and up to 4 to 5 years in milder climates (e.g., northern U.S. or Canada).

Another notable observation after 1,000 hours of treatment was the presence of varying degrees of fibrillation on the specimens without finishing protection, as shown in **Fig. 11**. This effect was particularly pronounced in unfinished trembling aspen, where localized areas of decay also developed a yellowish discolouration.

Fig. 11. Surface fibrillation observed after weathering in trembling aspen (left) and S-P-F (right) specimens.

Compared to S-P-F, trembling aspen exhibited greater colour stability, as shown in both the artificial accelerated and short-term natural weathering tests. This difference was consistently observed across various exposure durations, suggesting that aspen might possess inherent resistance to UV- and moisture-induced discolouration. Wood surfaces are prone to noticeable colour changes during weathering, particularly in the early stages of exposure [25]. Compared to softwoods, hardwoods generally exhibit greater colour stability under such conditions. For instance, Oberhofnerova et al. [25] found that spruce (*Picea abies* L.) underwent a total colour change (ΔE^*) of 34.1 after 12 months of natural weathering, whereas oak (*Quercus robur* L.) showed a smaller change of 23.0, indicating better colour retention. Similarly, Sahin et al. [26] reported that Scots pine (*Pinus sylvestris* L.) exhibited a lightness change (ΔL^*) of up to 37.2%, while beech (*Fagus sylvatica* L.) maintained more stable surface properties under comparable exposure conditions. These findings and the discovery from this study are reasonable and logic, as hardwoods generally contain less lignin than softwoods. Compared to cellulose and hemicellulose, lignin absorbs UV radiation more strongly, leading to surface discolouration and fibre loosening, thereby accelerating the weathering process [27].

Based on previous studies [14-16], it can be reasonably inferred that the 2,000-hour accelerated weathering treatment using ASTM G155 Cycle 1 may approximate the effects of about three years of natural weathering exposure. However, further research is needed to validate this conclusion.

4 Conclusions

Based on the above results and discussion, the following conclusions could be drawn:

1) Both short-term and accelerated weathering tests exhibited similar trends, as evidenced by surface greying and darkening, along with increases in average colour change (ΔE).

2) Finished trembling aspen siding specimens consistently exhibited greater colour stability than finished S-P-F ones, with average colour change values being 1.5 lower after the four-month natural weathering test and 2.2 lower after the 2,000-hour artificial accelerated exposure.

3) Both finished trembling aspen and S-P-F siding specimens had smaller ΔE values than unfinished ones, suggesting the finishing employed in this study effectively protected surface colour.

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CRediT authorship contribution statement

M.Z.: Investigation, Formal analysis, Writing - original draft. **Y.H.C. and M.G.**: Conceptualization, Funding acquisition, Supervision, Investigation, Writing - review. **M.Z. and D.W.**: Investigation. **M.G. and Y.H.C.**: Supervision, Investigation. **M.Z. and M.G.**: Writing - review and editing.

Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

Data Availability Statement

All data generated or analysed during this study are included in the article. Further details are available from the corresponding authors upon request.

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