

Wood weathering in fluorescent ultraviolet and xenon arc chambers

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Abstract

The artificial weathering of five wood species was compared in a modified fluorescent ultraviolet light and xenon arc accelerated-weathering chambers. Both chambers were equipped with water spray as part of the accelerated-weathering cycle. We measured and compared wood surface erosion on unfinished specimens of four softwoods and one hardwood after exposure to 2,400 hours of accelerated weathering. Very similar effects were seen for the two chambers. Our study confirmed the importance of a water spray system that simulates rainfall and washing action on the wood surface in the accelerated-weathering process. This system is indispensable for obtaining characteristic wood weathering degradation and significant wood surface erosion as seen with natural weathering.

Artificial weathering methods are useful tools for studying the durability of unfinished and finished wood products that will be used outdoors. Such weathering tests can accelerate the effects of natural weathering from 5 to 20 times depending on the exposure conditions chosen. They are valuable tools because their conditions can be controlled and reproduced (5,7). Because all the modes of natural weathering degradation cannot be simulated collectively (such as degradation by ultraviolet (UV) light, wetting by liquid water, and discoloration by mold and stain fungi), accelerated tests generally focus on the effects of UV light and moisture.

In preliminary studies, the Swiss Federal Laboratories for Materials Testing and Research (EMPA) used a modified fluorescent UV light accelerated-weathering chamber equipped with a water-condensation system. The initial results did not show the typical surface erosion of unprotected wood usually observed with carbon arc or xenon arc accelerated-weathering chambers fitted with water-

spray systems (2,6, 10). The main result observed in the EMPA studies was the usual yellow to brown discoloration of the wood surface, which is caused by UV light degradation.

The fluorescent UV light accelerated-weathering chamber is an elongated trapezoid. Only the most damaging part of the sunlight (low end of UV spectrum) is reproduced by eight fluorescent UV lamps (3). Moisture on the test surface is simulated by a condensation system and temperature is controlled by an air heater. There are no rotating elements in the chamber. Specimens are uniformly exposed by changing their position in the chamber periodically. However, because of insufficient moisture movement on the specimen surface in the chamber, degraded wood material is not removed from the surface. The washing action of water is essential for removing solubilized wood degradation products from the wood surface and for bleaching the wood. Washing with water also removes loosened wood fibers and particles produced during the weathering process and thus causes wood surface erosion (8,11), exposing a new layer of undegraded wood. For these reasons, EMPA added a water-spray system to the fluorescent UV light weathering apparatus. In preliminary tests with the modified apparatus, the appearance of specimens exposed to accelerated weathering was comparable to that of naturally weathered wood (12).

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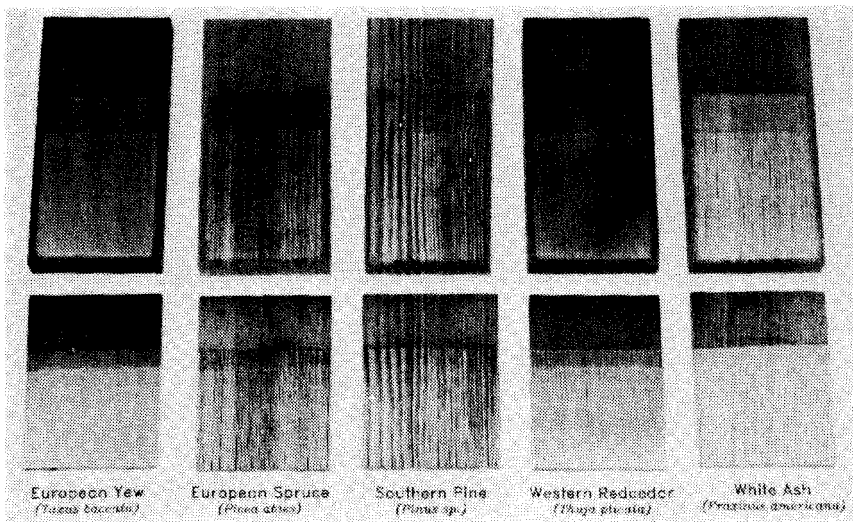


Figure 1, — One of three replicate sets of paired weathering specimens of five species. Top — fluorescent UV light chamber specimens; bottom — xenon arc chamber specimens. The top third of the specimen was protected against exposure and used as the reference surface.

TABLE 1. — Specimen specifications and experimental design for accelerated-weathering tests.

Light source	Specimens per species (no.)	Specimen size ^a (mm)	Chamber temperature (°C)	Exposure cycle (hr.)	
				Light	Water-spray
Fluorescent UV light (UVA-340)	3	150 by 75 by 18	60	5 ^b	1 ^b
Xenon arc (with borosilicate filter)	3	100 by 75 by 6	50	24	4 ^c

^a Longitudinal by radial by tangential dimensions. Different specimen sizes were used because of the size requirements of specimen holders of the two chambers.

^b Periods of light and water-spray were alternated.

^c During each 24-hour period, water-spray was turned on for a period of 4 hours.

The objective of our study was to compare the effects of accelerated weathering in the water-spray-modified fluorescent UV light weathering chamber and a standard xenon arc chamber, using a water-spray in conjunction with the UV light in both chambers. We compared the weathering and erosion rates of four softwoods and one hardwood.

Materials and methods

Experimental procedures

The amount of surface erosion, measured as depth of erosion of the earlywood and latewood bands of individual growth rings, has been shown to be a reliable measure of the severity of weathering effects on the wood surface (6,10). This technique for measuring surface erosion was used in our study. Because our study was designed to compare the weathering effects of two types of accelerated-weathering chambers, only unfinished solid wood was tested. Finished wood would require different methods to account for degradation of the finish.

Because of the distinct difference in density between earlywood and latewood, weathering processes are generally easier to study with softwoods than hardwoods. Western redcedar is particularly useful because of its fast erosion rate (6,10), which allows visible results after a short time. Measurements on hardwoods are mostly restricted to latewood. The large open vessels in the earlywood of ring-porous species do not allow accurate measurements. A measurement based on growth rings is not possible if the small differences in density in the species do not accentuate the earlywood and latewood bands.

Heartwood samples were cut from vertical-grained boards of two European softwood species (yew (*Taxus bac-*

cata) and spruce (*Picea abies*)), two American softwood species (southern pine (*Pinus sp.*) and western redcedar (*Thuja plicata*)), and one American hardwood species (white ash (*Fraxinus americana*)) (Fig. 1). The wood species were chosen to cover a wide range of bulk wood density values.

Three replicate sets of end-matched unfinished specimens of each species were exposed in either the fluorescent UV light or xenon arc accelerated-weathering chamber for a total of 2,400 hours of light using the exposure cycles shown in Table 1. For both weathering chambers, specimens were sprayed with water for 4 hours within a 24-hour period. This provided sufficient time for the specimens to dry between spraying periods.

The upper third of each specimen was covered with a steel plate (Fig. 1) to protect part of the surface from weathering and to serve as a reference point for measuring erosion. The depth of erosion of earlywood and latewood of five growth rings per specimen was measured microscopically at 600-hour intervals of light exposure as described previously (6). An average of the five readings per specimen was used for the evaluation.

Statistical analysis

For the initial analysis, average wood erosion values after 2,400 hours of exposure were used for direct comparison of the accelerated-weathering chambers; the values showed a good correlation between the two chambers (1). One disadvantage of this method is that it takes into consideration values at a specific timepoint only; it does not consider the trend over time. Thus, the method is highly sensitive to inaccurate readings at each timepoint and their variability. Moreover, the analysis has to be repeated at each measured timepoint to use all the recorded

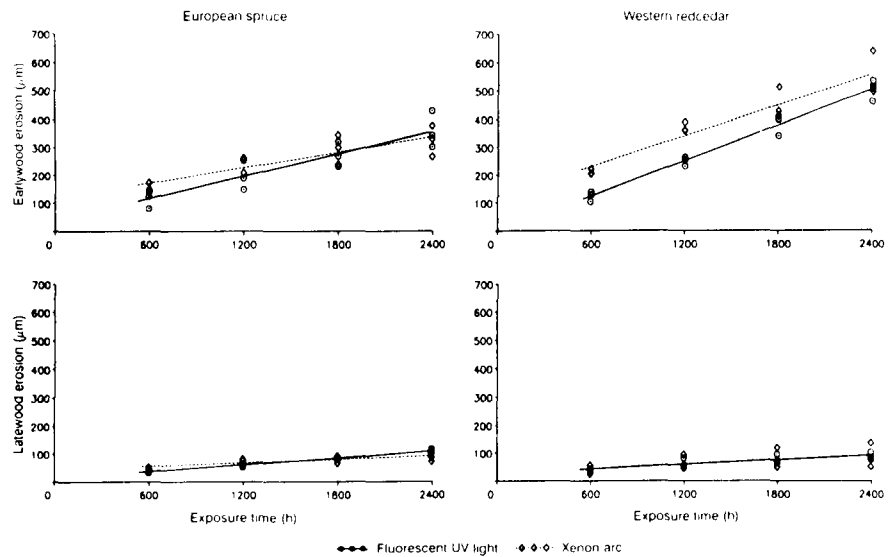


Figure 2. — Erosion rates of earlywood (top) and latewood (bottom) of European spruce and western redcedar artificially weathered in fluorescent UV light and xenon arc chambers. Each data point represents the average of five readings per specimen.

TABLE 2. — Erosion rates for different wood species.

Wood species	Wood density ^b (g/cm ³)	Erosion rate ^a							
		Xenon arc			Comparison of erosion rates ^c		Fluorescent UV light		
		Slope (μm/hr.)	Y-intercept (μm)	r ² (%)	Parallelism	Coincidence	Slope (μm/hr.)	Y-intercept (μm)	r ² (%)
Softwood									
European yew	0.754								
Earlywood		0.047	42.3	61	*	--	0.078	-1.5	95
Latewood		0.020	10.8	80	*	*	0.032	9.3	83
European spruce	0.510								
Earlywood		0.093	117.7	74	--	--	0.134	37.8	83
Latewood		0.020	44.2	61	*	*	0.040	13.8	98
Southern pine	0.753								
Earlywood		0.085	73.5	78	--	--	0.097	8.7	75
Latewood		0.032	30.0	88	--	*	0.022	5.3	40
Western redcedar	0.338								
Earlywood		0.184	122.3	88	--	*	0.213	-2.2	97
Latewood		0.028	27.8	32	--	--	0.028	26.5	70
Hardwood									
White ash	0.589								
Latewood		0.040	34.8	65	--	--	0.047	22.0	95

^a Erosion rates determined by fitting depth of erosion data as a function of time to a linear regression model ($Y = a + bx$). Y-intercept (a) and slope (b) are the parameter estimates of the model; r^2 is the coefficient of determination.

^b Average of three samples, calculated from weight and volume at 12 percent moisture content.

^c Comparison of two regression lines as described by Kleinbaum and Kupper (9). * = significant difference at the 95 percent confidence level.

information. Fluctuations in values between the time-points further complicate interpretation of the results.

A more comprehensive method uses the rate of erosion (a regression model that fits depth of erosion as a function of exposure time) as the basis of comparison. The best-fitting regression model may be different for individual specimens, but there is no reason to assume a general nonlinear relationship between the depth of erosion and the exposure time within the observed timeframe (4,13). Thus, we used a linear model in our study (Fig. 2). The equality of the two erosion rates per species was tested by a multivariable method (9), allowing the simultaneous comparison of slope and Y-intercept of two regression lines, and a statistical test for parallelism (equal slopes) or coincidence (no overall difference).

Results and discussion

The depth of erosion in the earlywood after 2,400 hours of exposure varied from around 100 μm with high-density European yew to about 700 μm with low-density western redcedar (Fig. 2). The range of the latewood erosion for all the species was much smaller; average latewood erosion was about 100 μm after 2,400 hours of accelerated weathering. The calculated erosion rates for all the species are compiled in Table 2.

As is usually observed with measurement of wood erosion caused by weathering, the variability of the readings was high. The standard deviation of the five erosion values within each specimen was slightly higher than the variability between the average values of the three replicates per species. Within and between specimens, coef-

ficients of variance ranged from 10 to 50 percent. Generally, the latewood erosion values varied to a greater extent than the earlywood erosion values. This was mainly caused by the often sharp-edged and fragile latewood band, which made focusing of the microscope used for measurement difficult (6). For this reason and because erosion in earlywood was deeper and more distinct than erosion in latewood, the earlywood measurement gave better and more reliable readings.

The deviation of the erosion rates from the expected zero Y-intercept (Table 2) may be explained by a slight nonlinearity of the erosion process during the first few hundred hours of exposure. Additional difficulties arose in determining the zero reference point on the unweathered part of the growth ring for the erosion measurements. Shrinkage and swelling of the wood during exposure can change the original zero point. This was a source of some inaccuracy for the absolute values of the readings. For this reason, regression lines were not forced through the zero point.

The Y-intercepts of the erosion rates of the xenon arc chamber specimens were somewhat higher than those of the fluorescent UV light chamber specimens (Table 2).

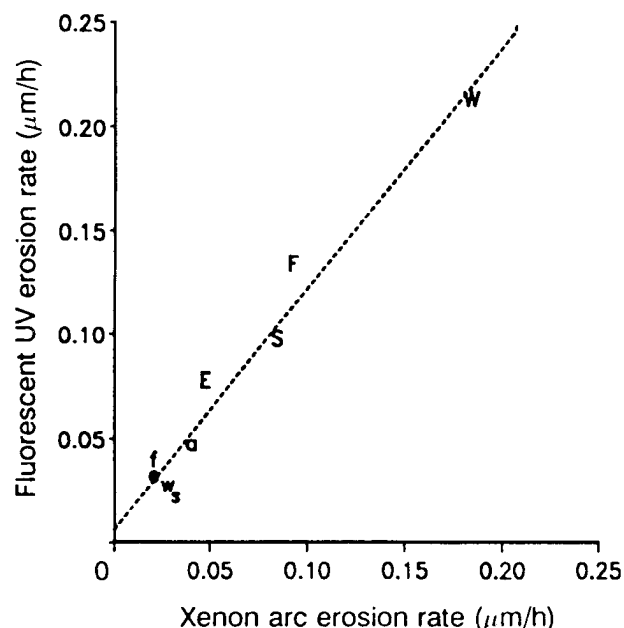


Figure 3. — Erosion rates (slopes of linear regression) of earlywood and latewood of the tested wood species. Common erosion rates of three samples per wood species are shown. E = European yew, F = European spruce, S = southern pine, W = western redcedar, and A = white ash. Uppercase letters refer to earlywood, lowercase to latewood. The equation for the slope is:

$$E_{r,QUV} = 0.006 + 1.164 E_{r,WOM}$$

where:

- E_r = erosion rate
- QUV = fluorescent UV light chamber
- WOM = xenon arc chamber (coefficient of correlation, $r = 0.98$)

This may be explained by the greater deformation of the xenon arc chamber specimens during the exposure because of their small (6 mm) thickness. Consequently, measurements of xenon arc chamber specimens are difficult to make and readings tend to be somewhat distorted. The specimens for the fluorescent UV light chamber were thicker (18 mm) and were less sensitive to severe splitting.

The slopes of the erosion rates represent the essential weathering action on the surface, giving the increase of depth of erosion per unit time. This trend over time is not subject to the restrictions mentioned with the Y-intercepts and was reliable with both types of specimens.

The statistical comparison (Table 2) per species shows no statistical differences of the erosion rates for most specimens. Even for the specimens that show a statistically significant difference, the real differences are negligibly small. The overall correspondence of the results from the fluorescent UV light and xenon arc chambers is very good. A direct comparison of the erosion rates (slopes of linear regression) for all the species (Fig. 3) also shows a high correlation and conformity of the erosion effects of the two chambers.

The timing of weathering cycles greatly influences the development of weathering stresses on the wood surface. Three hours of UV light plus a 3-hour water-spray cycle in the fluorescent UV light chamber reduced erosion of the specimens compared to 5-hour UV light plus a 1-hour water-spray cycle. This can be explained by the lower surface temperature of the wood during the shorter light phase. To reach the set chamber temperature (60°C) on the wood surface requires approximately 3 hours of light exposure. For effective surface degradation, this temperature should be maintained for some additional time; a period of 5 hours was selected for our study.

Concluding remarks

The surface erosion of wood specimens artificially weathered in a modified type of fluorescent UV light accelerated-weathering chamber showed good correlation with that of specimens weathered in a standard xenon arc accelerated-weathering chamber; both chambers were equipped with a water-spray system. We conclude that, with the weathering cycles used, both accelerated-weathering chambers exerted a similar effect on unfinished solid wood. The results confirm that, whatever the UV light source, a water-spray system is essential for removing UV-light-degraded wood material from the weathered surface and for achieving the characteristic surface erosion of natural weathering.

More research on various accelerated-weathering methods focused on effective weathering cycles and their correlation to outdoor weathering will lead to a wider use of these methods. A standardization of accelerated-weathering procedures currently under study in Europe will permit comparison of results from different tests.

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