EROSION RATES OF WOOD DURING NATURAL WEATHERING. PART III. EFFECT OF EXPOSURE ANGLE ON EROSION RATE

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ABSTRACT

This is the third in a series of reports on the erosion rates of wood exposed outdoors near Madison, Wisconsin. The specimens were exposed at an orientation of 90° or 45° facing south or horizontally (0°) for 10 years. Erosion was measured annually for the first 8 years and after 10 years. The erosion rates of earlywood (springwood) and latewood (summerwood) were determined for smooth-planed vertical-grained and flat-grained lumber (radial and tangential surfaces, respectively). Wood species included Douglas-fir, loblolly pine, southern pine, western redcedar, northern red oak, and yellow-poplar. Large differences were observed in earlywood and latewood erosion rates during weathering. For most species, the erosion rate increased as the angle of exposure decreased from 90° to 0°. A notable exception to this was observed for western redcedar, which had the fastest erosion at the 45° exposure. For some species, particularly western redcedar and southern pine (earlywood), erosion rates differed for tangential and radial surfaces. Little difference was observed between erosion rates of tangential and radial surfaces for the other wood species.

Keywords: Weathering, erosion, flat grain, vertical grain, wood properties.

INTRODUCTION

The term weathering, as used in this report, describes the degradation of wood exposed above ground that is initiated by ultraviolet (UV) radiation in sunlight. The rate of degradation is increased by water (rain, dew, snow), changes in relative humidity, increased temperature, and windblown sand and/or other particulates. Attack by decay fungi is not considered weathering, nor is mildew growth on the wood surface, which usually accompanies weathering. Weathering of wood is primarily a surface phenomenon that results in the slow erosion of wood fibers from the surface.

In the first paper of this series, we investigated the effects of weathering on redwood,

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western redcedar, Douglas-fir, and southern pine.[2] The second paper explored the effects of weathering on ponderosa pine, lodgepole pine, Engelmann spruce, western hemlock, and red alder.[3] The rate of erosion for smooth-planed vertical-grained lumber was about 40 to 60 μm/year for all species except western redcedar, which had an erosion rate of about 95 μm/year.

The background and literature review for all the papers in this series were presented in Part I. Although there is a vast amount of information available on wood weathering, little information has been published on the actual erosion rates of wood and wood-based composites exposed outdoors for 10 or more years.

The objective of the research reported here was to determine differences in erosion rate of various wood species measured over a period of 10 years, particularly with regard to the effects of angle of exposure, type of wood (earlywood or latewood), and grain angle (radial or tangential).

EXPERIMENTAL

Materials

Smooth-planed lumber was used for all specimens. Except for loblolly pine, the lumber was used as received from a local lumber yard. Loblolly pine was obtained from authentic stock at the Forest Products Laboratory. Specimens were cut 30 by 6 by 100 mm (100 mm longitudinal). The 30- by 100-mm surface that was exposed was either radial (vertical-grained) or tangential (flat-grained). Wood species were Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), loblolly pine (*Pinus taeda* L.), southern pine (*Pinus sp.*), western redcedar (*Thuja placata* Donn ex D. Don), northern red oak (*Quercus rubra* L.), and yellow-poplar (*Liriodendron tulipifera* L.). The top 35 mm of the surface (length) of each specimen was protected from the weather by a 55-mm-wide strip of stainless steel oriented perpendicular to the longitudinal axis.

Methods

Specimens were fully exposed to the weather on a test fence 15 km west of Madison, Wisconsin, for 10 years (1983 to 1993). Specimens were oriented at three angles of exposure: (1) vertically facing south with the longitudinal axis (fiber direction) at a 90° angle, (2) 45° facing south with the longitudinal axis oriented north/south (45° exposure), or (3) horizontally with the longitudinal axis oriented north/south (0° exposure). Specimens were removed from the test periodically for erosion measurements.

The erosion rates of earlywood and latewood bands were measured annually for the first 8 years and after 10 years using a microscopic technique (Black and Mraz 1974; Feist and Mraz 1978). For each exposure angle (0°, 45°, or 90°) and grain angle (tangential or radial), three measurements were made on each of three replicates, providing nine observations for each erosion determination.

RESULTS AND DISCUSSION

Average erosion measurements for earlywood and latewood of the test species at 4, 8, and 10 years are shown in Table 1. The raw data are available from the Forest Products Laboratory Web site (www.fpl.fs.fed.us). Individual plots of the data are shown in Figs. 1 to 6 for Douglas-fir, loblolly pine, an undefined species of southern pine, western redcedar, northern red oak, and yellow-poplar, respectively. The bars indicate the standard deviation of each average; they are offset for clarity. The plots for each experimental condition and species are labeled according to type of wood (earlywood or latewood) and grain angle (radial or tangential). Thus, an earlywood band on a radial surface is designated ER and a latewood band on a tangential surface LT.

[2] Williams, R. S., M. T. Knaebe, P. G. Sotos, and W. C. Feist. Erosion Rates of Wood During Natural Weathering Part I. Effects of Grain Angle and Surface Texture. This issue, 31–42.

[3] Williams, R. S., M. T. Knaebe, and W. C. Feist. Erosion Rates of Wood During Natural Weathering Part 2. Earlywood and Latewood Erosion. This issue, 43–49.

TABLE 1. *Erosion of earlywood and latewood on smooth-planed surfaces of various wood species after outdoor exposure.*[a]

		Erosion (μm) after various exposure times[c]					
		4 years		8 years		10 years	
Wood species	Avg SG[b]	LW	EW	LW	EW	LW	EW
Loblolly pine	0.66	80	205	160	345	220	490
Southern pine	0.57	95	330	180	640	195	670
Yellow-poplar	0.47	—	220	—	530	—	640
Douglas-fir	0.48	75	255	175	605	225	590
Northern red oak	0.57	180	245	340	555	440	750

[a] Specimens were exposed vertically facing south. Radial surfaces were exposed with the grain vertical.
[b] SG is specific gravity.
[c] All erosion values are averages of nine observations (three measurements of three specimens). EW denotes earlywood; LW, latewood.

The trends and differences shown in the plots (Figs. 1–6) were confirmed by statistical tests. A segmented regression consisting of two straight lines that intersect at a joint point was fit to the data from each specimen using a nonlinear regression program. Using this type of model, it is possible to estimate which joint point allows the best fit of the overall data. In 55 of the 177 specimens, a joint point was estimated between 6 and 9 years. Given our concern about possible decay in specimens after 6 years of exposure, we decided to include data from only the first 6 years in subsequent analyses.

For almost all experimental conditions and species, a straight line regression was fit using the 1- to 6-year data of each specimen, and the slope of each regression was used as a measure of erosion rate. The regression analysis was not forced through 0. (In a few cases, erosion was insufficient for measurement; for example, erosion of red oak earlywood in the first 3 years of exposure (Fig. 5).) The R^2 values for each of these regression fits was typically above 0.90 for each specimen. This resulted in measurements of erosion rates for each combination of species, type of wood, grain orientation, and exposure angle. The mean and standard deviation values for these combinations are listed in Table 2. Trends in the average slopes include a general decrease in erosion rate with change in angle of exposure from 0° to 90°, more rapid erosion of earlywood compared to latewood, and only slight differences between the erosion of radial and tangential surfaces. Differences among species are also apparent.

An analysis of variance (ANOVA) was performed to evaluate the statistical significance of the trends apparent in Table 2. Because this ANOVA showed significant interactions, we examined the trends for each species and earlywood/latewood combination separately by performing another ANOVA, followed by a Tukey multiple comparison test at the 0.01 level of significance. Results of these tests are shown in Table 3.

The least severe exposure angle was 90°, as expected (Table 3). Results of comparison of the 0° and 45° exposures initially appeared inconsistent. Since UV irradiance is at a maximum just a few degrees above a horizontal exposure, we expected an increase in erosion with a decrease in the angle of exposure. In most cases, this was not the case. The most severe exposure was generally at 45°. We hypothesize that degradation was more rapid at 45° as a result of more rapid washing of the degradation products from the surface and the cleansing action of rain. Degradation products and dirt tended to accumulate on the horizontal (0°) surface, thus protecting it from the light.

The data in Table 3 show the significance of the angle of exposure. The rapid erosion of red oak latewood at 0° and 45° was quite surprising; at 0° exposure, erosion of red oak was faster than that of western redcedar (105 versus 77 μm/year, Table 2). The specific gravity values of red oak (dry) and western redcedar

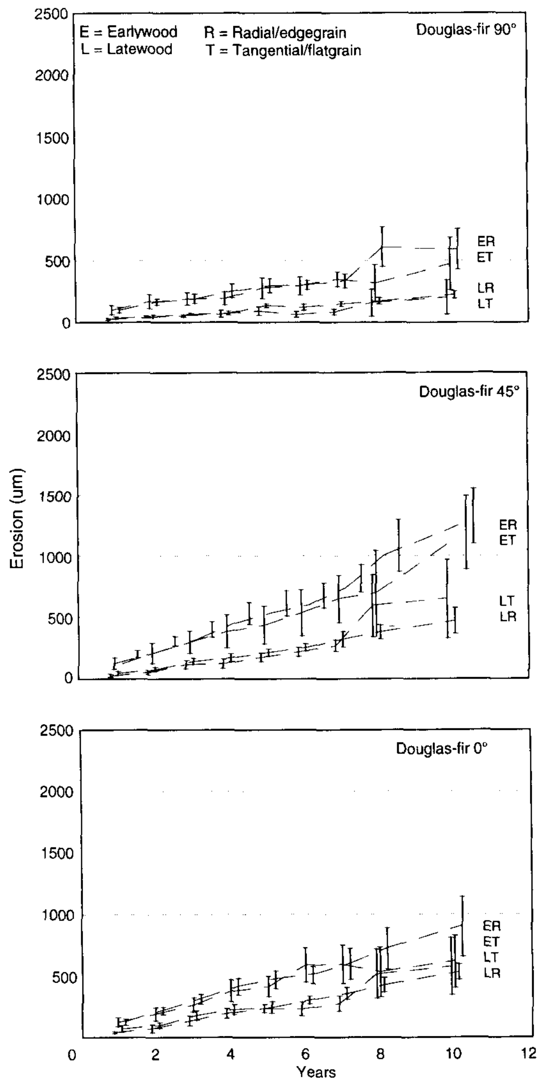

FIG. 1. Erosion of radial and tangential surfaces of Douglas-fir at various angles of exposure as a function of exposure period (average of three measurements on three replicate specimens). Bars indicate standard deviation and are offset for clarity.

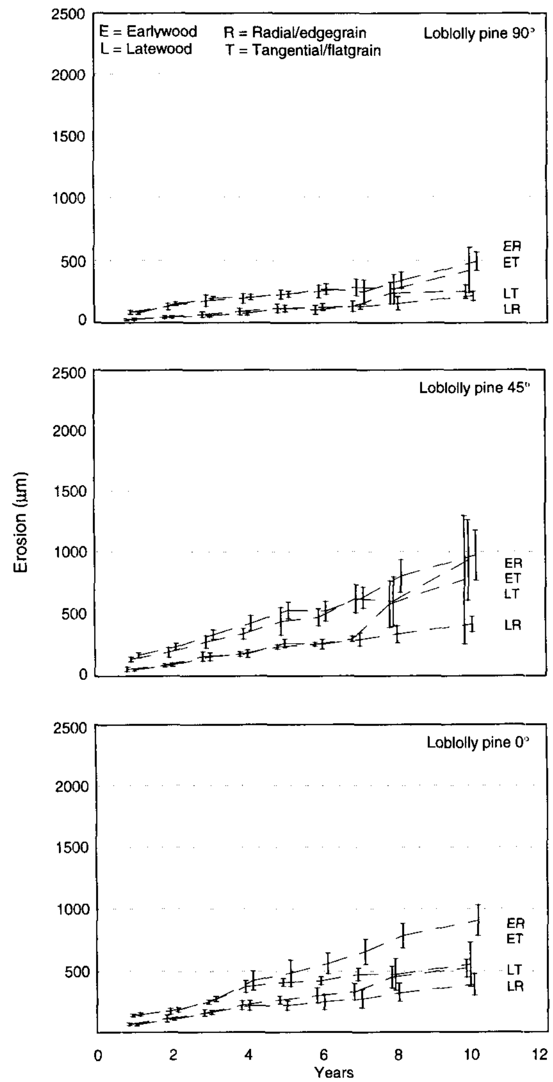

FIG. 2. Erosion of radial and tangential surfaces of loblolly pine at various angles of exposure as a function of exposure period (average of three measurements on three replicate specimens). Bars indicate standard deviation and are offset for clarity.

are 0.63 and 0.32, respectively. On the basis of wood specific gravity, the erosion of red oak should be slower. Indeed, at the 90° angle of exposure, erosion of red oak earlywood was much slower than that of western redcedar (131 versus 35 µm/year, Table 2). This difference in erosion rates for red oak at different exposure angles can probably be attributed to difficulties in measurement; consistent readings were difficult to obtain because of the large vessels in this species. If fact, it was not possible to accurately measure earlywood erosion on the tangential surfaces of red oak. Incipient decay may have also been an important factor.

Yellow-poplar is a diffuse, porous, fine-

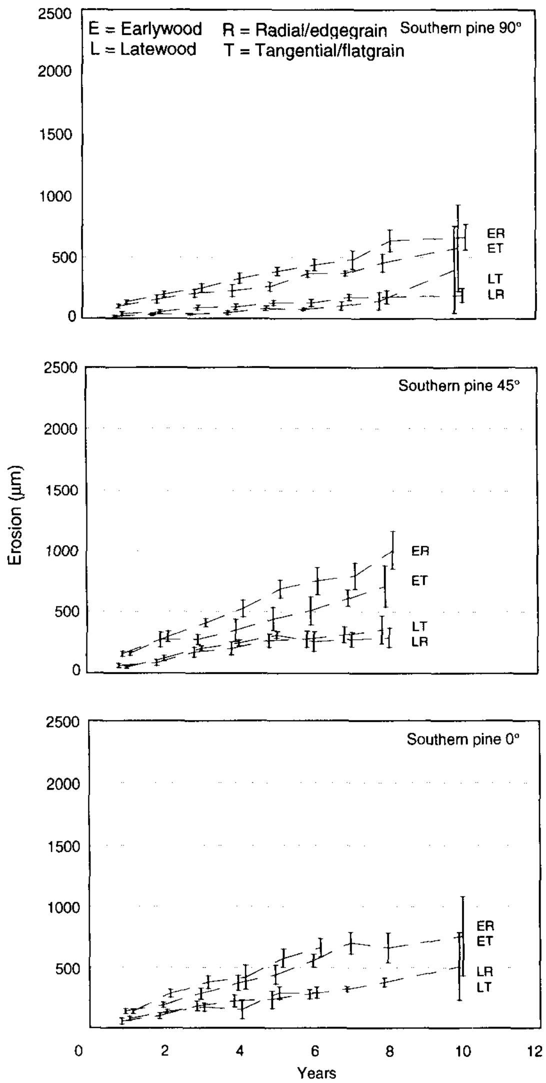

FIG. 3. Erosion of radial and tangential surfaces of southern pine at various angles of exposure as a function of exposure period (average of three measurements on three replicate specimens). Bars indicate standard deviation and are offset for clarity.

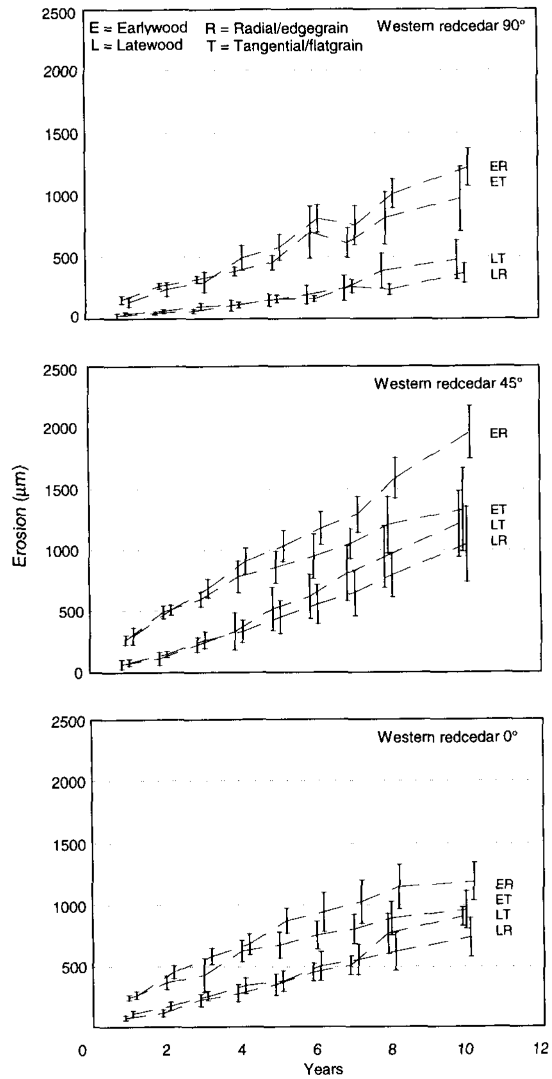

FIG. 4. Erosion of radial and tangential surfaces of western redcedar at various angles of exposure as a function of exposure period (average of three measurements on three replicate specimens). Bars indicate standard deviation and are offset for clarity.

grained wood with a specific gravity slightly greater than that of western redcedar. Like red oak, yellow-poplar has large vessels, which may have caused more rapid erosion of this species at the 0° and 45° exposures compared to western redcedar. In addition, incipient decay probably contributed to faster erosion at these exposure angles. Both red oak and yellow-poplar are very decay prone; specimens exposed at 0° and 45° are more likely to stay wet longer than specimens exposed at 90° and thus are more prone to decay.

Grain orientation did not have a significant (α = 0.01) effect on erosion rate except for southern pine and western redcedar earlywood (Table 3). In general, the erosion rate of the

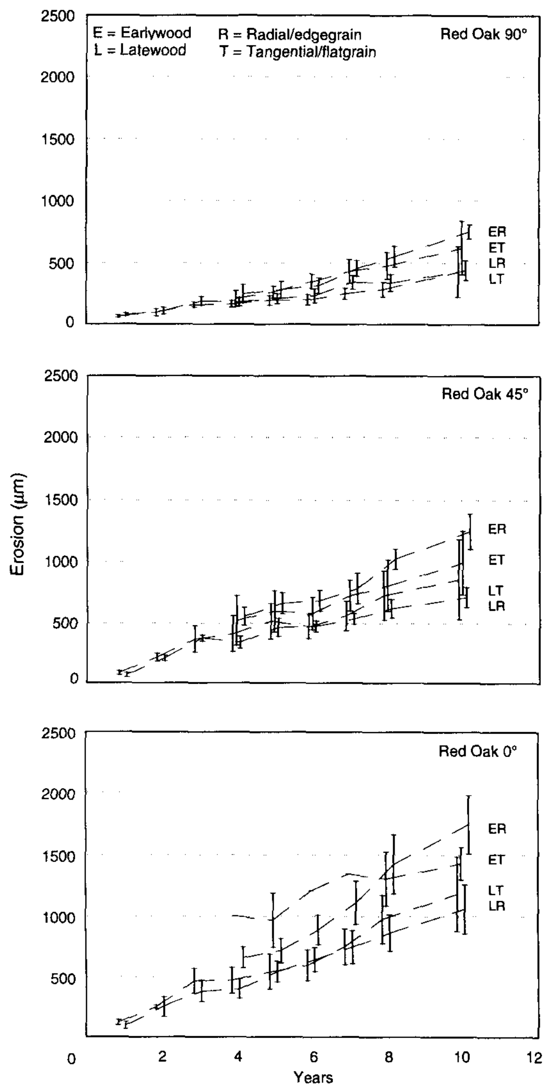

FIG. 5. Erosion of radial and tangential surfaces of northern red oak at various angles of exposure as a function of exposure period (average of three measurements on three replicate specimens). Bars indicate standard deviation and are offset for clarity.

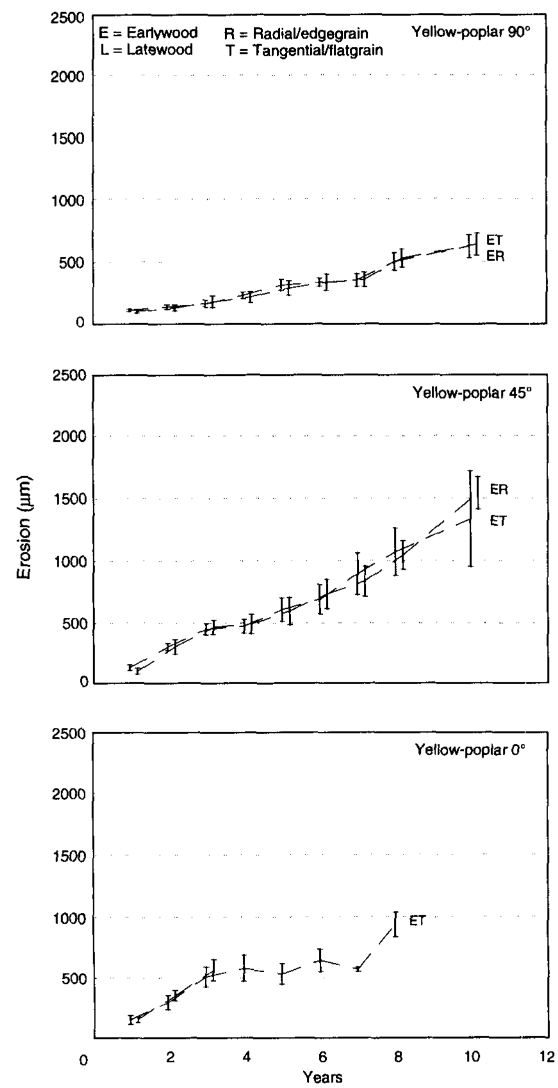

FIG. 6. Erosion of radial and tangential surfaces of yellow-poplar at various angles of exposure as a function of exposure period (average of three measurements on three replicate specimens). Bars indicate standard deviation and are offset for clarity.

radial surfaces was slightly higher than that of the tangential surfaces; the difference is statistically significant only for southern pine and western redcedar earlywood. These results agree with those of Parts I and II of this series.

Typical erosion rates for the test species are shown in Table 4. The earlywood and latewood erosion rates were determined for the radial grain angle (0–6 year exposure). Average erosion for earlywood and latewood is rounded to the nearest 5 μm/year. For many specimens, average erosion was not computed because the differences in erosion rate between earlywood and latewood were too large to be meaningful. As was shown in Part I of

TABLE 2. *Erosion rate (slope) and standard deviation of earlywood and latewood radial and tangential surfaces during 6 years of natural weathering for various wood species.*[a]

Species	Erosion rate at various exposure angles (μm/year)					
	0°		45°		90°	
	Radial	Tangential	Radial	Tangential	Radial	Tangential
Douglas-fir						
Earlywood	81 (11)	92 (16)	97 (5)	79 (12)	42 (3)	37 (5)
Latewood	48 (6)	45 (5)	42 (2)	38 (4)	20 (3)	10 (2)
Loblolly pine						
Earlywood	89 (16)	63 (4)	78 (8)	70 (9)	34 (5)	32 (2)
Latewood	39 (6)	50 (1)	44 (6)	41 (1)	20 (2)	18 (4)
Southern pine						
Earlywood	102 (5)	87 (4)	123 (15)	71 (17)	62 (7)	46 (4)
Latewood	44 (3)	42 (10)	48 (9)	47 (4)	20 (2)	16 (5)
Western redcedar						
Earlywood	135 (6)	103 (16)	177 (13)	134 (3)	131 (11)	96 (15)
Latewood	77 (1)	76 (7)	96 (9)	119 (16)	26 (2)	35 (3)
Northern red oak						
Earlywood	114 (45)[b]	—[c]	67 (8)	—	35 (7)	—
Latewood	105 (11)	95 (19)	80 (7)	83 (19)	30 (7)	27 (2)
Yellow-poplar						
Earlywood	209 (39)[d]	94 (21)	117 (11)	108 (6)	48 (6)	49 (3)
Latewood	—[e]	—	—	—	—	—

[a] Erosion is average of three slopes computed from linear regression of erosion data over years. Standard deviation (values in parentheses) was calculated on basis of all observations.

[b] Data were obtained for years 4, 5, and 6 only.

[c] Erosion rates of earlywood bands on tangential surface were extremely difficult to measure because of large open vessels; those data were not used in these analyses.

[d] Data were collected for years 1, 2, and 3 only (Fig. 6c).

[e] Latewood erosion was not measured for yellow-poplar because bands were not easily visible; in most cases, erosion was the same as that for earlywood.

this series, it takes several years for earlywood/latewood erosion rates to stabilize.

The erosion rates for Douglas-fir and loblolly pine were only 3 and 2.5 μm/year, respectively. This is considerably less than that for ponderosa pine (40 μm/year), lodgepole pine (40 μm/year), Engelmann spruce (45 μm/year), and western hemlock (50 μm/year), as reported in Part II (see footnote 2). We attribute this slower rate to the dense latewood bands in Douglas-fir and loblolly pine. The loblolly pine had an average growth rate of 6 rings/inch (2.5 rings/cm) and rather high specific gravity (0.66, Table 1). The difference in the erosion rates between loblolly pine and the other southern pines used in this study can be attributed to the difference in specific gravity values. Southern pine had an average specific gravity of 0.57 and an average growth rate of 10 rings/inch (4 rings/cm). The average erosion rate for Douglas-fir and loblolly pine (earlywood and latewood) exposed at 90° was about 30 and 25 μm/year, respectively, considerably less than that for softwoods such as ponderosa pine, lodgepole pine, Englemann spruce, and western hemlock.

TABLE 3. *Results of ANOVA test of equality followed by Tukey test at $\alpha = 0.01$ level for 1 to 6 years of exposure.*[a]

Wood species	Type of wood	Grain direction	Exposure angle
Douglas-fir	Earlywood	R T	45 0 90
	Latewood	R T	0 45 90
Loblolly pine	Earlywood	R T	0 45 90
	Latewood	T R	0 45 90
Northern red oak	Earlywood	R T	0 45 90
	Latewood	R T	0 45 90
Southern pine	Earlywood	R T	45 0 90
	Latewood	R T	45 0 90
Western redcedar	Earlywood	R T	45 0 90
	Latewood	T R	45 0 90
Yellow-poplar	Earlywood	T only[b]	45 0 90

[a] Values connected by the same line are not significantly different. Values increase from right to left.

[b] Insufficient data were obtained for radial surface exposures to make a comparison.

TABLE 4. *Typical erosion rates for earlywood and latewood of various species during 6 years outdoor exposure near Madison, Wisconsin, at different exposure angles.*[a]

Species	Earlywood (μm/year)			Latewood (μm/year)			Average erosion[b] per 100 years (mm)		
	90°	45°	0°	90°	45°	0°	90°	45°	0°
Douglas-fir	42	97	81	20	42	48	3	—	-
Loblolly pine	34	78	89	20	44	39	2.5	—	—
Southern pine	62	123	102	20	48	44	—	—	—
Western redcedar	131	177	135	26	96	77	—	—	—
Northern red oak	35	67	114	30	80	105	3	7.5	11
Yellow-poplar	48	117	209	—	—	—	—	—	—

[a] Data from vertical grain (radial surface) exposure of earlywood and latewood.
[b] Extrapolation of average of earlywood and latewood erosion rounded to nearest 5 units. Where the difference in erosion rate between earlywood and latewood was large, average erosion is not given.

CONCLUSIONS

The erosion rates of all species were considerably higher at the 45° angle of exposure than at 90°. For many species, erosion was about twice as fast for the 45° exposure. Most species showed little difference in erosion between the 0° and 45° exposures. Although UV radiation is higher for horizontal specimens (0° exposure), we hypothesize that the decrease in the washing action of water and the build-up of degradation products and dirt on the surface probably protected these specimens to some extent. This more rapid degradation would be expected to have a great effect on the service life of wood products used for roofing and decks.

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