EROSION RATES OF WOOD DURING NATURAL WEATHERING. PART II. EARLYWOOD AND LATEWOOD EROSION RATES

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(Received February 2000)

ABSTRACT

This is the second in a series of reports on the erosion rates of wood exposed outdoors near Madison, Wisconsin. In the work reported here, the erosion rates of earlywood and latewood were determined for smooth-planed vertical-grained lumber for an exposure period of 14 years. The specimens were oriented vertically, facing south; erosion was measured annually for the first 6 years and biannually the remainder of the exposure. Wood species were ponderosa pine, lodgepole pine, Engelmann spruce, western hemlock, and red alder. Large differences were observed between earlywood and latewood erosion rates during weathering. Erosion rates varied from 33 μm/year for lodgepole pine latewood to 58 μm/year for western hemlock and red alder earlywood. In general, no practical differences in erosion were observed for different orientations of the specimens on the test fence (vertical or horizontal longitudinal axis). Some specimens showed considerable decay after 10 years of exposure.

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

INTRODUCTION

Weathering is 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. Weathering of wood is primarily a surface phenomenon that results in the slow erosion of wood fibers.

In the first paper of this series, we investigated the weathering of redwood, western redcedar, Douglas-fir, and southern pine.[2] That study showed a significant difference in earlywood and latewood erosion rates of western redcedar and redwood during the first 7 years of weathering; after 7 years, earlywood and latewood erosion rates were about the same. For Douglas-fir and southern pine, significant differences in earlywood/latewood erosion

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[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. Submitted to Wood and Fiber Science.

continued after 7 years. The erosion rate of vertical-grained lumber was considerably faster than that of flat-grained plywood. However, only slight differences were observed for saw-textured as opposed to smooth plywood. The erosion rates confirmed the effect of wood specific gravity; species with higher specific gravity weathered more slowly.

The chemistry, mechanism, and rate of weathering and species effects have been studied for many years. Feist (1990) and Feist and Hon (1984) described in detail the mechanisms of wood degradation in aboveground exposure. Much of the information on weathering rates has been obtained from exposure of wood to high-intensity artificial UV radiation. Although a vast amount of information is available on wood weathering, little information has been published on actual erosion rates of wood and wood-based composites exposed outdoors for 10 or more years. Browne (1960) reported that the average erosion rate for most commercial American softwoods is about 6 mm per century. Feist and Mraz (1978) found good correlation between outdoor erosion rates and erosion rates measured using artificial UV radiation. These researchers also found good correlation between erosion rate and wood density. Additional literature on erosion rates of wood was cited in Part I of this series.

The objective of the research reported here was to determine differences in erosion rates measured over 14 years for various wood species, particularly with regard to the effects of proportion of earlywood to latewood and orientation of wood grain.

EXPERIMENTAL

Materials

Smooth-planed lumber was used as received from a local lumber yard. Specimens were cut 55 by 112 by 16 mm (radial by longitudinal by tangential), and the radial (vertical-grained) surface was exposed to the weather. Wood species tested were ponderosa pine (*Pinus ponderosa,* Dougl. ex Laws), lodgepole pine (*Pinus contorta,* Dougl. ex Loud.), Engelmann spruce (*Picea engelmannii,* Parry ex Engelm.), western hemlock (*Tsuga heterophylla,* (Raf.) Sarg.), and red alder (*Alnus rubra,* Bong.). Half of the exposed area of each specimen was protected from the weather by a 55-mm-wide strip of stainless steel oriented perpendicular to the longitudinal axis.

Methods

The specimens were fully exposed to the weather on a test fence 15 km west of Madison, Wisconsin, for up to 14 years (1979 to 1993). Ponderosa pine was evaluated for only 10 years because the specimens showed severe decay after this time; other wood species exhibited decay to varying extents. Specimens were exposed to the weather on a vertical fence facing south. They were oriented with their longitudinal axis (fiber direction) vertical or horizontal (Fig. 1). Specimens were removed only for periodic erosion measurements. For red alder, only earlywood was measured because the latewood band was too thin to measure accurately.

The erosion rates of earlywood and latewood bands were measured annually for the first 6 years and biannually from 8 to 14 years using a microscopic technique (Black and Mraz 1974; Feist and Mraz 1978). For each wood species, three measurements were made on each of three replicates, providing nine observations for each erosion determination.

A segmented regression that included an estimate of a joint point between the two segments was conducted using a standard statistical package. If a joint point was found, a straight line was fitted for each segment for each experimental condition (e.g., earlywood/vertical orientation) using the same statistical package to give the slope and intercept of each segment. Since the segmented regression indicated a joint point at 10 years for about one-half the plots and considerable decay was observed in many specimens after 10 years, only the 0- through 10-year data were used to determine erosion rates.

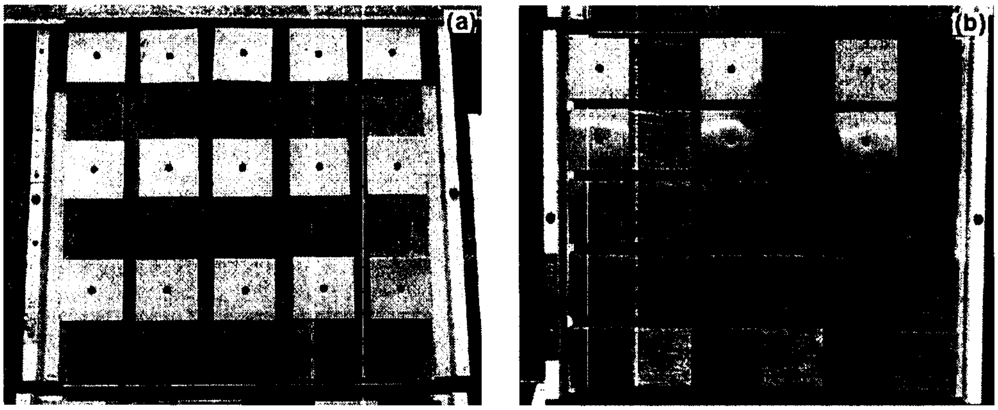

FIG. 1. Orientations of specimens on test fence relative to longitudinal axis: (a) vertical, (b) horizontal.

RESULTS AND DISCUSSION

Average erosion measurements for earlywood and latewood after 4, 8, and 10 years of exposure are listed in Table 1. The raw data used for all calculations are available at the Forest Products Laboratory Web site (www.fpl.fs.fed.us). Individual plots of the data are shown in Figs. 2 to 6 for ponderosa pine, lodgepole pine, Engelmann spruce, western hemlock, and red alder, respectively. The bars indicate the standard deviation of each average; they are offset for clarity. The plots include erosion measurements for horizontal and vertical orientations (Fig. 1) and earlywood and latewood. Earlywood/vertical orientation is designated EV and latewood/horizontal orientation, LH.

As shown in Part I of this series, erosion seemed to be greater in year 5 (1983 to 1984) than in other years (Figs. 2–6). Although the change in the rate of erosion was not as great as that reported earlier, the data seem consistent with the previously reported erosion rates. In reviewing the weather data for this period, particularly the reported UV irradiance for North America, we found nothing that could readily explain the greater erosion rate during year 5. We had expected year-to-year fluctuations in measured erosion but cannot explain the unusually high erosion during that year. Variability in the weather from year to year and our inability to quantify this variability are two of the problems we have encountered in analyzing data obtained from long-term outdoor testing.

Unlike the data shown in Part I, particularly for western redcedar and redwood, none of the data for the work evaluated here showed a

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

Wood species	Avg SG[b]	Erosion (μm) after various exposure times[c]					
		4 years		8 years		10 years	
		LW	EW	LW	EW	LW	EW
Ponderosa pine	0.35	130	270	315	445	430	570
Lodgepole pine	0.38	105	255	265	465	320	580
Englemann spruce	0.36	125	320	310	545	390	650
Western hemlock	0.34	145	320	310	575	415	680
Red alder	0.39	—	295	—	545	—	620

[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.

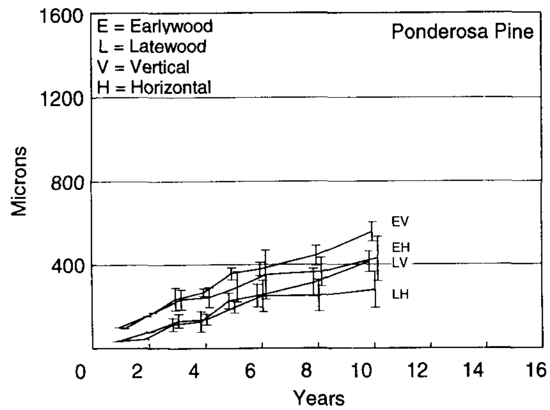

FIG. 2. Erosion of vertical-grained ponderosa pine lumber as a function of years of exposure (average of measurements on three replicate specimens). Bars indicate standard deviation and are offset for clarity.

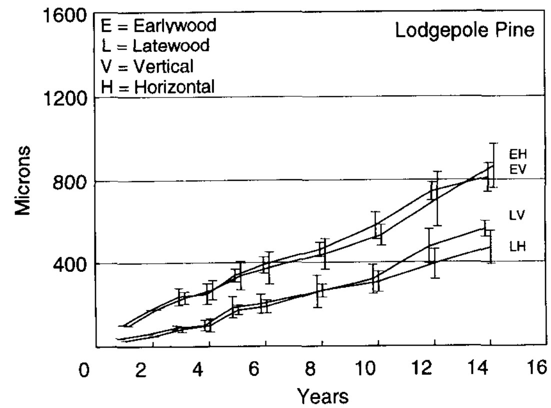

FIG. 3. Erosion of vertical-grained lodgepole pine as a function of years of exposure (average of measurements on three replicate specimens). Bars indicate standard deviation and are offset for clarity.

change in erosion rate between 6 and 8 years of exposure. The unusually high erosion during year 5 did not seem to affect the segmented regression. The segmented regression analysis showed joint points in the data at 10 years for Engelmann spruce earlywood, lodgepole pine earlywood and latewood, and western hemlock earlywood. Ponderosa pine earlywood had a joint point at 6 years. These joint points can be explained by the occurrence of decay. For example, ponderosa pine showed signs of decay after 6 years of exposure and was badly decayed by 12 years. No measurements were made on ponderosa pine after 10 years. At least one specimen each of lodgepole pine and western hemlock showed decay and had to be rejected. We therefore decided to fit only the 0- to 10-year data to a straight-line regression.

Earlywood and latewood erosion

For smooth-planed vertical-grained ponderosa pine, erosion rates of earlywood and latewood were significantly different (Fig. 2). The erosion rates were slightly different for vertical and horizontal grain orientations from years 6 through 10. We do not know whether decay in these specimens affected erosion measurements. The other wood species showed similar differences between earlywood and latewood erosion, but no practical differences attributable to orientation of the longitudinal axis (Figs. 3–6). Since the specific gravity values of these species are not much different than that of redwood, it is somewhat surprising that these wood species did not show a change in erosion rate at about 7 years of exposure, as shown for redwood in Part I of this series. One hypothesis to explain this observation is that decay occurred in these specimens before weathering had progressed to the point where we could observe this

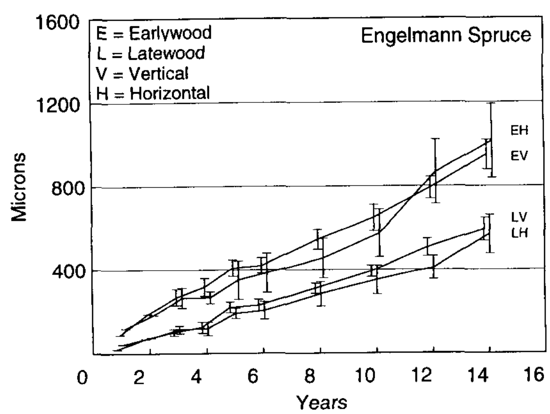

FIG. 4. Erosion of vertical-grained Engelmann spruce lumber as a function of years of exposure (average of measurements on three replicate specimens). Bars indicate standard deviation and are offset for clarity.

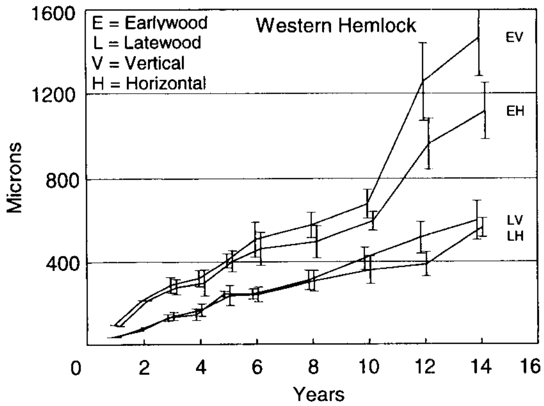

FIG. 5. Erosion of vertical-grained western hemlock as a function of years of exposure (average of measurements on three replicate specimens). Bars indicate standard deviation and are offset for clarity.

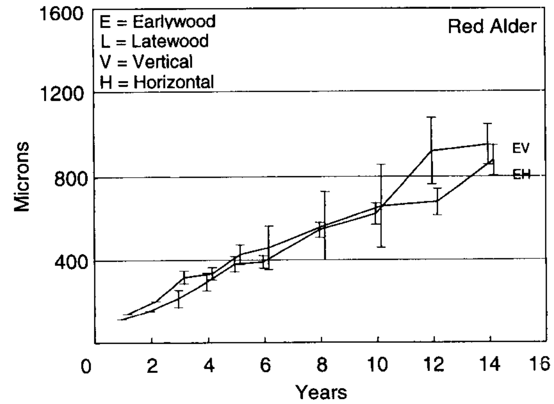

FIG. 6. Erosion of vertical-grained red alder as a function of years of exposure (average of measurements on three replicate specimens). Bars indicate standard deviation and are offset for clarity.

change. It may also be possible that the segmented regression could not detect any changes in erosion rate between years 6 and 8 because the changes caused by decay were predominant. A linear fit of the erosion data for earlywood and latewood was performed to obtain the slope (erosion rate), Y-intercept, and R^2 value for each species (Table 2).

The erosion of ponderosa pine, lodgepole pine, western hemlock, and Engelmann spruce was similar to that found in our earlier study (part 1) for Douglas-fir and southern pine. The wide latewood bands in these species were rather resistant to erosion and breaking. Some differences in the erosion patterns were observed in the analysis of micrographs (Fig. 7). The erosion of ponderosa pine and Douglas-fir seemed to be dependent on wood density. Erosion was greatest for wood formed at the beginning of the growth season and decreased with the increase in cell density through that growth period. There also tended to be cracking at the latewood/earlywood boundary at the end of the growing season. Lodgepole pine, western hemlock, and Engelmann spruce showed cracking and greater erosion toward the center of the earlywood ring. We cannot explain this result. We observed that as erosion progressed, the earlywood became shaded by the latewood and the earlywood erosion became "V-shaped," as can be seen in the erosion of western redcedar. The cross-section of red alder revealed no earlywood/latewood differences. No obvious differences were observed between horizontal and vertical orientations of the longitudinal axis.

TABLE 2. *Linear fit of earlywood and latewood erosion data from 10 years of natural weathering for various wood species.*

Species	Erosion rate[a] Yint/slope/R^2 (μm/μm/yr (%))	Significance level[b] earlywood/latewood
Ponderosa pine		
Earlywood	88/42 (0.79)	0.0910
Latewood	10/35 (0.81)	
Lodgepole pine		
Earlywood	78/49 (0.93)	0.0001
Latewood	−6/33 (0.91)	
Engelmann spruce		
Earlywood	82/54 (0.86)	0.0001
Latewood	−6/38 (0.95)	
Western hemlock		
Earlywood	89/58 (0.90)	0.0001
Latewood	8/39 (0.92)	
Red alder		
Earlywood	82/58 (0.82)	—
Latewood	—	—

[a] Yint is Y-intercept.
[b] Comparison of slopes of regression lines for 0- to 10-year measurements. Numbers indicate significance level between earlywood and latewood slopes.

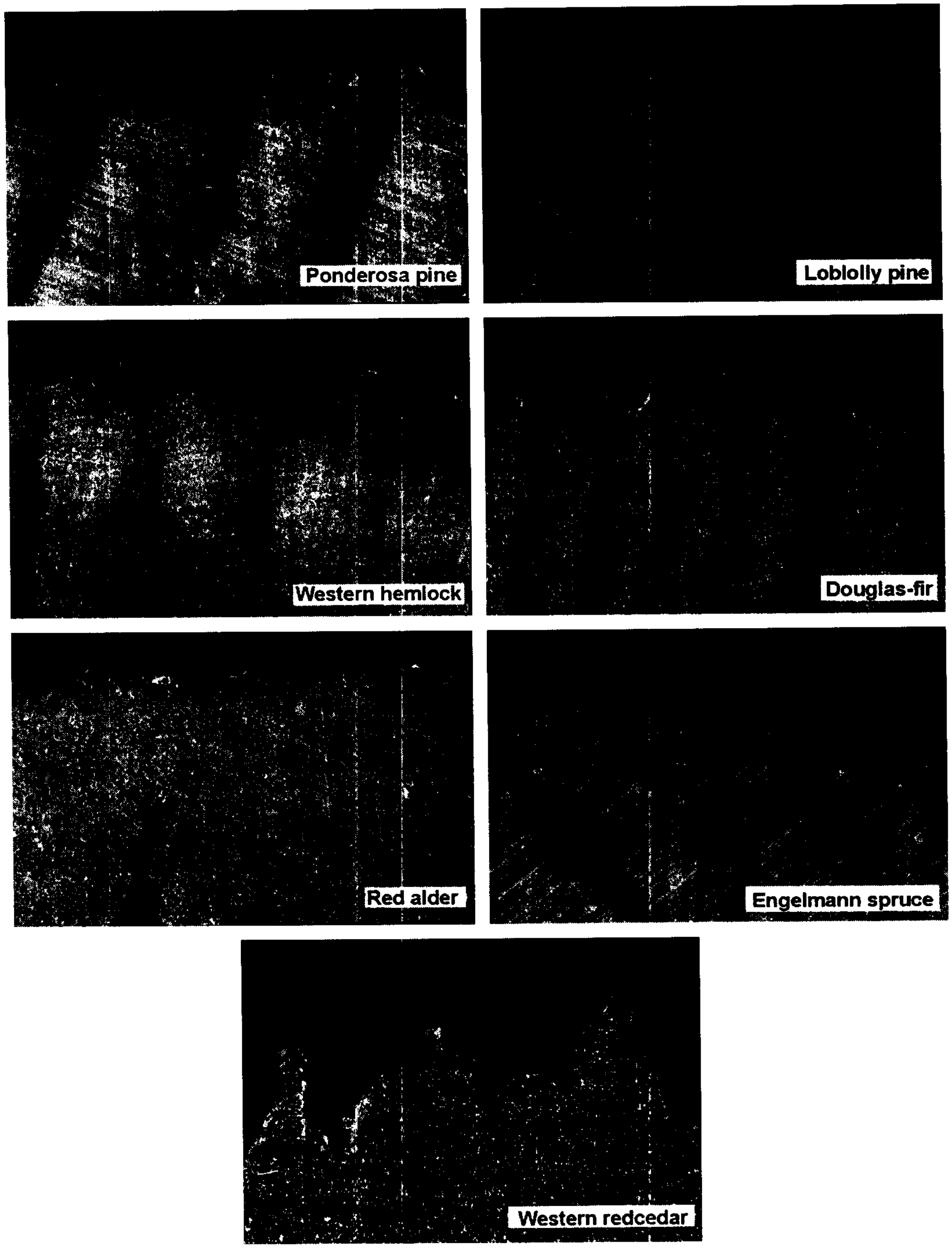

FIG. 7. Erosion of earlywood and latewood in weathered specimens of various species.

TABLE 3. *Typical erosion rates for earlywood and latewood for various species measured during 10 years outdoor exposure near Madison, Wisconsin.*[a]

Species	Early-wood (μm/yr)	Late-wood (μm/yr)	Average erosion (μm) per year[b]	Erosion (μm) per 100 years[c] (mm)
Ponderosa pine	42	35	40	4.0
Lodgepole pine	49	33	40	4.0
Englemann spruce	54	38	45	4.5
Western hemlock	58	39	50	5.0
Red alder	58	—	60	6.0

[a] Data from vertical and horizontal grain exposures were combined to compute earlywood and latewood erosion rates.
[b] Average erosion of earlywood and latewood rounded to nearest 5 units.
[c] Extrapolated from average earlywood and latewood erosion rates rounded to nearest 0.5 mm.

Species differences

Typical erosion rates for different wood species are shown in Table 3. The rates listed for earlywood and latewood erosion were determined from the combined horizontal and vertical grain exposures for the first 10 years of the study. The average erosion rates for earlywood and latewood were arbitrarily rounded to the nearest 5 μm/year. In general, softwood weathering has been reported as about 6 mm/century. Extrapolation of our 0- to 10-year measurements to 100 years indicated slightly slower erosion rates.

CONCLUSIONS

The average erosion rates for earlywood and latewood extrapolated from the 0- to 10-year data for ponderosa pine, lodgepole pine, Engelmann spruce, and western hemlock varied from 4 to 5 mm/century. This is slightly less than the 6 mm/century erosion rate usually given for softwoods. The erosion rate for earlywood alone is less than 6 mm/century. The erosion rate for red alder earlywood, 58 μm/year, was the same as that for western hemlock earlywood, which is not surprising given the similar specific gravity of these species. The thin latewood bands of red alder broke off as the earlywood eroded and had little effect on the rate of erosion. Differences in surface morphology can affect weathering of the surface. Wood species with wide latewood bands weather differently than do species with thin latewood bands. Such species may not undergo a change in the erosion rate within the first 10 years, as shown previously for western redcedar and redwood.

ACKNOWLEDGMENTS

We appreciate work by James Evans (statistical analysis of data), Tom Kuster (micrographs), and John Gangstad (measurement of specimen erosion).

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