EROSION RATES OF WOOD DURING NATURAL WEATHERING. PART I. EFFECTS OF GRAIN ANGLE AND SURFACE TEXTURE

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ABSTRACT

This is the first in a series of reports on the erosion rates of wood exposed outdoors near Madison, Wisconsin. The specimens were oriented vertically, facing south; erosion was measured annually for the first several years and biannually for the remainder of the exposure. In the work reported here, the erosion rates of earlywood and latewood were determined for smooth-planed vertical-grained lumber and abrasive-planed and saw-textured flat-grained plywood for an exposure period of 16 years. Lumber species were southern pine, western redcedar, Douglas-fir, and redwood; plywood species were western redcedar, Douglas-fir, and redwood. Erosion rates varied from 34 μm/year for southern pine latewood to 101 μm/year for western redcedar earlywood. Large differences were observed between earlywood and latewood erosion rates during the first 7 years of weathering, but not during subsequent years. A significant change in the erosion rate of just the latewood was observed for redwood, western redcedar, and Douglas-fir after approximately 7 years of exposure, and for southern pine, a significant change occurred after approximately 12 years of exposure. The erosion rates of vertical-grained lumber were higher than those of flat-grained plywood. Only slight differences were observed for saw-textured as compared to smooth plywood.

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. The

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average erosion rate for most commercial American softwoods is about 6 mm per century (Browne 1960).

Much of the information on the rate of wood degradation has been obtained from artificial weathering studies. Futo (1976) exposed wood specimens to UV radiation or thermal treatment and evaluated degradation by weight loss. Williams and Feist (1985) used artificial weathering to evaluate the effects of chromic acid and chromium nitrate treatment of wood surfaces to retard weathering. Williams (1987) used artificial UV radiation to determine the effects of acid on the rate of erosion; degradation was determined by measuring the change in wood mass. Arnold et al. (1991) measured wood erosion of European yew (*Taxus baccata*), Norway spruce (*Picea abies*), southern pine, western redcedar, and white ash (*Fraxinus americana*) during 2,400 hours of artificial weathering. Derbyshire et al. (1997) used artificial weathering to determine the activation energies for several wood species; wood degradation was determined by loss in tensile strength.

Studies of natural weathering have addressed the mechanisms of wood degradation and the effects of exposure conditions. Feist (1990) and Feist and Hon (1984) described the mechanisms of wood degradation in aboveground exposure. In a study on the correlation of natural weathering with loss of tensile strength, Derbyshire et al. (1995a, b) identified three phases of degradation (surface structural change, degradation of lignin, and degradation of cellulose). They also compared the degradation of six softwood species and developed a mathematical expression that fit strength loss of thin sections from a short period of natural weathering (Derbyshire et al. 1996). Yata and Tamura (1995) found that the depth of wood degradation remained constant after 6 months of outdoor weathering. Substantial delignification of the surface of radiata pine (*Pinus radiata*) was found after as few as 3 days of outdoor exposure (Evans et al. 1996). Evans (1996) also studied the effect of exposure angle on the natural weathering of radiata pine. The chemistry, mechanism, and rate of weathering and species effects are the subject of a forthcoming review article by Williams.

Some researchers have compared the results of natural and accelerated weathering. 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. They reported similar erosion rates for earlywood and latewood of some species after an initial 2-year period. Deppe (1981) compared 12- to 60-week accelerated aging with 3- to 8-year natural weathering of wood-based composites but was primarily interested in water absorption, thickness swelling, and strength properties. Derbyshire et al. (1995a, b) compared natural and artificial weathering by assessing the degradation of small strips of wood.

Little information has been published on erosion rates of wood and wood-based composites exposed outdoors for more than a few years. Evans (1988) evaluated the degradation of thin wood veneers exposed outdoors for up to 100 days, using "weight loss" as the unit of measurement. Sell and Leukens (1971) weathered 20 wood species outdoors for 1 year at 45° south, but their main interest was in the discoloration of wood. Evans (1989) used scanning electron microscopy (SEM) to show the loss of wood, primarily degradation of the middle lamella, following 2 years of natural weathering. Yoshida and Taguchi (1977) noted loss of strength in plywood exposed to natural weathering for 7 years, and Ostman (1983) measured the surface roughness of several wood and wood-based products after 4 years of natural weathering. Bentum and Addo-Ashong (1977) evaluated cracking and surface erosion of 48 timber species, primarily tropical hardwoods, after 5 years of outdoor weathering in Ghana. Weathering characteristics of tropical hardwoods from Taiwan during both outdoor exposure and accelerated weathering have also been reported (Wang 1981, 1990: Wang et al. 1980).

The objective of the research reported here

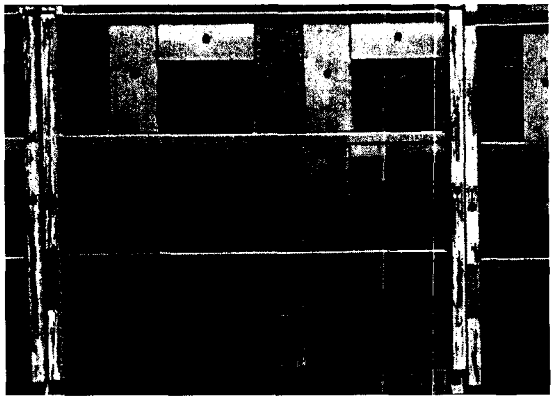

FIG. 1. Orientation of specimens on test fence.

was to determine differences in erosion rate measured over 16 years for various wood species. The effects of the earlywood to latewood ratio, grain orientation (vertical- or flat-grained), surface texture (smooth-planed or saw-textured), and orientation of longitudinal axis (horizontal or vertical) of the wood were also determined.

EXPERIMENTAL

Materials

Lumber and plywood were used as received from a local lumber yard. The lumber consisted of smooth-planed vertical-grained western redcedar (*Thuja placata* Donn ex D. Don), redwood (*Sequoia sempervirens* D. Don (Endl.)), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and southern pine (*Pinus* sp.). The plywood was either abrasive-planed (sanded) or saw-textured western redcedar, redwood, and Douglas-fir. Lumber and plywood specimens were 100 mm wide by 125 mm long by 16 mm thick; length was cut in the fiber direction. Half of the exposed area of each specimen was covered with a stainless steel plate oriented across the board or plywood perpendicular to the fiber direction (Fig. 1).

Methods

The specimens were fully exposed to the weather for 16 years (1977 to 1993) on a vertical south-facing test fence located 15 km west of Madison, Wisconsin. The specimens were oriented with their longitudinal axis (fiber direction) vertical or horizontal (Fig. 1). They were removed from the test fence only for periodic erosion measurements.

The erosion rates of earlywood and latewood bands were measured annually for the first 8 years and biannually from 8 to 16 years using a microscopic technique (Black and Mraz 1974; Feist and Mraz 1978). For each type of wood surface, 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 are listed in Table 1. The raw data are available on the Forest Products Laboratory Web site (www.fpl.fs.fed.us). Plots of erosion as a function of time for various species are shown in Figs. 2 to 8. The plots are labeled to define the experimental parameters: earlywood/latewood, horizontal/vertical orientation, and smooth/saw-textured (rough) surface. For example, earlywood/vertical orientation/smooth surface is designated EVS; latewood/horizontal/smooth, LHS. The bars indicate the standard deviation of each average; they are offset from the year for clarity. Since only the mean erosion rate was recorded for the first 5 years of exposure, there are no error bars for the data for this period.

The vertical-grained smooth-planed lumber was placed on the fence with its longitudinal axis oriented horizontally or vertically. Erosion was measured for both earlywood and latewood for both orientations to give four plots for each of the four lumber types (Figs. 2, 4, 6, and 8). The horizontal (flat)-grained plywood included both smooth and rough surfaces. The plots for plywood include vertical and horizontal orientation of the longitudinal axis for both earlywood and latewood as well as smooth and rough surfaces (Figs. 3, 5, and 7). Species included western redcedar, red-

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		12 years		14 years		16 years	
		LW	EW	LW	EW	LW	EW	LW	EW	LW	EW	LW	EW
Western redcedar plywood	—	170	580	290	920	455	1,095	615	1,165	805	1,355	910	1,475
Redwood plywood	—	125	440	295	670	475	800	575	965	695	1,070	845	1,250
Douglas-fir plywood	—	110	270	190	390	255	500	345	555	425	770	515	905
Douglas-fir	0.46	105	270	210	720	285	905	380	980	520	1,300	500	1,405
Southern pine	0.45	135	320	275	605	315	710	335	710	445	1,180	525	1,355
Western redcedar	0.31	200	500	595	1,090	765	1,325	970	1,565	1,160	1,800	1,380	1,945
Redwood	0.36	165	405	315	650	440	835	555	965	670	1,180	835	1,385

[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.

wood, and Douglas-fir. Four plots are shown for both earlywood and latewood. For example, latewood with a vertical orientation and a rough surface is designated LVR; earlywood/horizontal/smooth, EHS.

For western redcedar lumber, an increase in the erosion rate (slope) of the plots occurred at about 7 years of exposure (Fig. 2). Similar changes in erosion rate were observed for western redcedar plywood, redwood lumber and plywood, and Douglas-fir lumber and plywood (Figs. 3, 4, 5, 6, and 7, respectively). For southern pine, the erosion rate increased at 12 years of exposure (Fig. 8).

To verify this visual impression of a change in erosion rate, a segmented regression consisting of two straight lines that intersect at a joint point (change in slope) was fit to the data 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 and to test whether the slopes and intercepts of the intersecting lines are the same or different. The segmented regression was fit separately for each species, wood type (lumber or plywood), and earlywood/latewood combination. A segmented linear regression that included an estimate of a joint point between the two segments was conducted using a commercial statistical package. A straight line was fitted for each segment for each experimental condition (earlywood/vertical/smooth (EVS)) using the same statistical package to give the

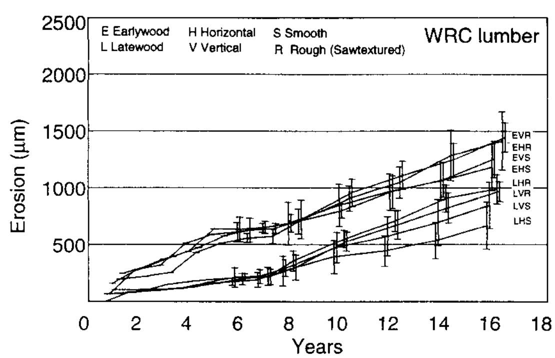

FIG. 2. Erosion of western redcedar (WRC) vertical-grained lumber as a function of years of exposure (average of measurements on three replicate specimens). Bars indicate standard deviation at each average (bars offset for clarity).

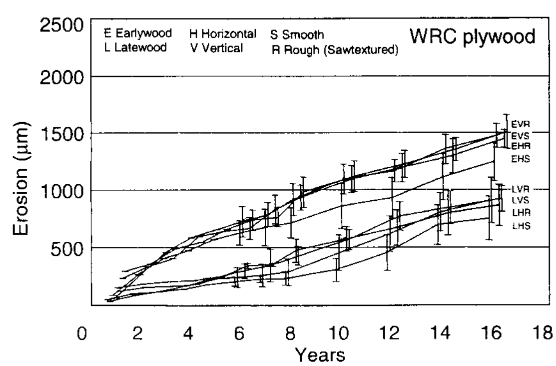

FIG. 3. Erosion of flat-grained WRC plywood as a function of years of exposure (average of measurements on three replicate specimens).

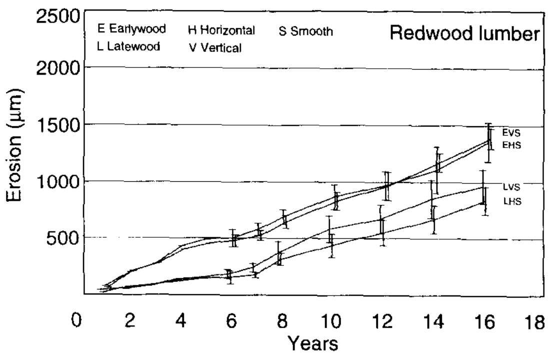

FIG. 4. Erosion of vertical-grained redwood lumber as a function of years of exposure (average of measurements on three replicate specimens).

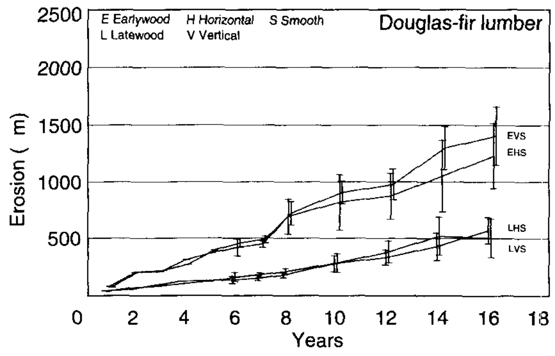

FIG. 6. Erosion of vertical-grained Douglas-fir lumber as a function of years of exposure (average of measurements on three replicate specimens).

slope and intercept of each segment. The slopes of the various segments before and after 7 years of exposure were tested for their difference, and levels of significance were determined; for example, the slope (erosion rate) of earlywood as opposed to latewood for western redcedar from 0 to 6 years exposure (EVS vs. LVS).

The segmented regression of all the data confirmed a significant joint point at about 7 years of exposure for latewood of all species except southern pine (Table 2). Earlywood did not show a statistically significant joint point at this time. However, earlywood erosion between the 7th and 8th years of exposure seemed unusually high, particularly for western redcedar and Douglas-fir lumber. These apparent discontinuities in the data can be observed in Figs. 2 to 7.

Under the assumption that some change (change in slope for latewood or unusually high erosion as reflected in earlywood) occurred for all specimens (except southern pine) at about 7 years of exposure, the data were separated into two groups. One group consisted of the 0- through 6-year exposure data for western redcedar, redwood, and Douglas-fir; and the second group consisted of the 8- through 16-year data for these species. The southern pine data were separated into two groups with a break at 12 years. The slope before and after this fixed joint point, the r^2 value, and the time to the joint point are shown in Table 3.

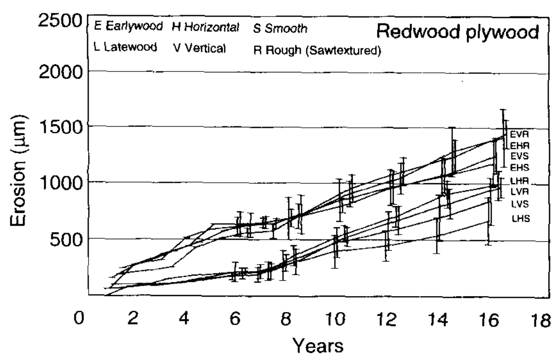

FIG. 5. Erosion of flat-grained redwood plywood as a function of years of exposure (average of measurements on three replicate specimens).

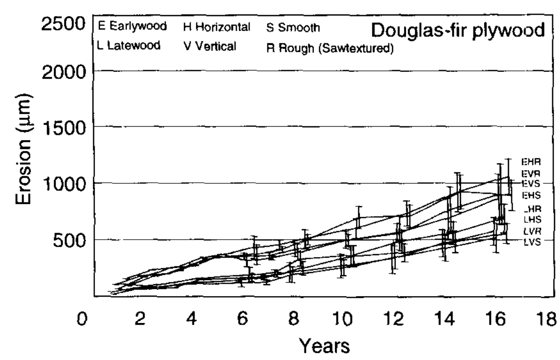

FIG. 7. Erosion of flat-grained Douglas-fir plywood as a function of years of exposure (average of measurements on three replicate specimens).

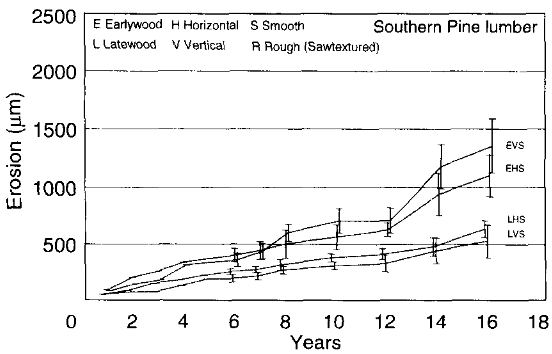

FIG. 8. Erosion of vertical-grained southern pine lumber as a function of years of exposure (average of measurements on three replicate specimens).

TABLE 2. *Joint point for segmented regression of earlywood and latewood erosion measurements.*[a]

Species	Wood type	Earlywood or latewood	Years of exposure
Western redcedar	Lumber	Latewood	7
	Plywood	Latewood	7
Redwood	Lumber	Latewood	6
	Plywood	Latewood	7
Douglas-fir	Lumber	Latewood	8
	Plywood	Latewood	7
Southern pine	Lumber	Earlywood	12

[a] Segmented regression was performed with a commercial statistical package.

We considered several reasons for the change in erosion rate at about 7 years of exposure. In reviewing the weather conditions, particularly the reported UV irradiance for North America, apparently nothing could readily explain the change in erosion rate at this time. A different technician did the measurements between the 8th and 10th years, but this seemed to have no effect on the measurements. We expected year-to-year fluctuations in the measured erosion, but the observed change at 7 years seemed to indicate a change in erosion rate for latewood. We have no explanation for the unusually high erosion for earlywood during that year. The variability in the weather from year to year and our inability to quantify this variability constitute one difficulty encountered in analyzing data obtained from long-term outdoor testing. However, it is interesting to note that no clear change in erosion rate occurred for southern pine at 7 years (Fig. 8), and the change for Douglas-fir is not very obvious, particularly for latewood (Figs. 6 and 7). This seems to indicate that the change in erosion rate might have had more to do with intrinsic wood properties than with the weather.

Vertical-grained lumber

For vertical-grained lumber specimens, the slope of the curves generally tended to increase with time for latewood and decrease with time for earlywood (Figs. 2, 4, 6, and 8). For western redcedar and redwood, the transition was rather abrupt at 7 years of exposure. Both species showed similar changes in slope throughout the exposure period. For Douglas-fir, the slopes were nearly identical after 16 years of exposure (Fig. 6). For southern pine, the erosion rates for earlywood and latewood were quite different before and after 12 years of exposure (Fig. 8).

For smooth-planed vertical-grained western redcedar, the plots show significant difference between earlywood and latewood during the first 7 years of exposure. Previous work had established that the erosion rate of wood decreases as wood density increases (Sell and Feist 1986). In general, the latewood bands of western redcedar and redwood are thinner and less dense than those of southern pine and Douglas-fir. During the early phase of weathering of vertical-grained lumber, we observed that the earlywood eroded more quickly, exposing the more resistant latewood bands. As the latewood bands became exposed, weathering occurred at the sides as well as the top of the bands. The earlywood bands became valley-shaped whereas the latewood bands became peaked (Fig. 9). Erosion of the latewood was much slower than that of the earlywood until the latewood became exposed. Then, the erosion rate of the latewood approximated that of the earlywood (Table 3). For example, the earlywood and latewood erosion rates (EV/LV) from 1 to 6 years for vertically exposed western redcedar were 111 and 63 μm/year, respectively. This difference in slope, as shown in Fig. 2, is significant (Table 3, P = 0.0001). For 8 to 16 years, the earlywood and latewood erosion rates were 109 and 98 μm/year, respectively; this difference is not significant (Table 3, P = 0.6102). Note: For the reader's convenience, these erosion rates are highlighted (boldfaced) in Table 3.

Similar trends were observed for redwood, but values for Douglas-fir and southern pine lumber reflect the greater difference between earlywood and latewood for these species. We also observed that latewood bands on western redcedar and redwood lumber were rather thin compared to those of Douglas-fir and southern pine. As erosion progressed, these thin bands tended to break off. The increased exposure of the latewood as the earlywood weathered and the breakage of the exposed latewood bands probably caused more rapid erosion of the latewood after 7 years of exposure. The wider latewood bands of Douglas-fir and southern pine were less prone to break, and so there was considerable difference in the earlywood/latewood erosion rate after 7 years.

This raises an interesting question concerning the relative importance of density on long-term erosion of wood surfaces. We believe that there is an inverse relationship between density and erosion rate. However, in vertical-grained wood, earlywood becomes sheltered by latewood as erosion progresses, whereas a larger area of latewood is exposed as weathering progresses. This increased area leads to an overall increase in erosion rate. It appears that retardation of erosion depends on the density and anatomy of the wood. For lower density wood species with thin latewood bands, the transition occurs at about 7 years of exposure. For higher density wood species with wide latewood bands, this transition is not as apparent and may occur later.

Another factor could have affected erosion measurements. Southern pine showed obvious signs of decay after 10 years and a change in erosion rate at that time. During the later years of the exposure, some of the other wood species may have started to decay. Although there were no obvious signs of decay in these species, we cannot be sure that incipient decay was not present. Thus, decay may have affected the erosion rate in these species as well. Several precautions could have minimized decay, such as mounting the specimens to prevent moisture entrapment and using end-grain sealers. In contrast to the erosion of western redcedar and redwood earlywood, which decreased during the later years of exposure, the erosion of southern pine earlywood apparently increased abruptly after 10 years of exposure. We suspect that wood decay caused this change.

The erosion of Douglas-fir earlywood seemed to show a trend similar to that of southern pine. Although these specimens showed no obvious sign of decay, it is certainly possible that more rapid erosion in the last few years of exposure may have been caused by incipient decay.

Flat-grained plywood

The most notable difference for flat-grained plywood was between earlywood and latewood erosion rates during the first 6 years of exposure (Figs. 3, 5, and 7). For example, the erosion rate of smooth western redcedar plywood, as determined from regression analysis of the data for the first 6 years of exposure, was 131 μm/year for earlywood and 43 μm/year for latewood (Table 3, EVS and LVS, P = 0.0001). Saw-textured western redcedar showed a similar trend (EVR = 90 μm/year, LVR = 40 μm/year; P = 0.0001). Similar results were obtained for redwood and Douglas-fir.

Like the erosion of vertical-grained lumber, the erosion rates for flat-grained plywood determined from linear regression of the 8- through 16-year data were similar for earlywood and latewood (Table 3). The difference in slopes was not significant for smooth western redcedar plywood during the later years of exposure (EVS = 68 μm/year, LVS = 80 μm/year; P = 0.4852). The similarity of the slopes can be seen in the plots of western redcedar and redwood (Figs. 2 and 4).

TABLE 3. *Erosion rates and significance levels obtained for comparison of slopes.*[a]

Variable	1 to 6 years: P-value EV/EH EV/LV LV/LH	1 to 6 years: Erosion rate/year Yint/slope/R^2 (μm/μm/yr (%))	Rate change[b] (Yes/no)	Rate change[b] (P-value)	8 to 16 years: Erosion rate/year Yint/slope/R^2 (μm/μm/yr (%))	8 to 16 years: P-value EV/EH EV/LV LV/LH
Western redcedar lumber (vertical-grained)						
Smooth						
EVS	0.8643	115/**111** (0.92)	No	0.9274	235/**109** (0.82)	0.3886
EHS	**0.0001**	101/113 (0.95)	No	0.1909	284/94 (0.86)	**0.6102**
LVS	0.4992	−9/**63** (0.84)	—	0.1245	−200/**98** (0.71)	0.5617
LHS		3/58 (0.89)	Yes	0.0833	−152/85 (0.79)	
Western redcedar plywood (flat-grained)						
Smooth						
EVS	0.571	0/**131** (0.91)	Yes	0.0001	379/**68** (0.89)	0.8469
EHS	**0.001**	35/106 (0.92)	Yes	0.0499	188/65 (0.59)	**0.4852**
LVS	0.133	−5/**43** (0.84)	Yes	0.0479	−340/**80** (0.71)	0.6495
LHS		27/30 (0.93)	Yes	0.0035	−370/71 (0.77)	
Saw-textured						
EVR	0.7256	198/**90** (0.95)	Yes	0.0208	463/64 (0.83)	0.7799
EHR	**0.0001**	153/93 (0.94)	Yes	0.0052	456/61 (0.83)	0.9232
LVR	0.0100	62/**40** (0.85)	Yes	0.0586	−51/63 (0.78)	0.4232
LHS		123/27 (0.89)	—	0.1377	72/50 (0.55)	
Redwood lumber (vertical-grained)						
Smooth						
EVS	0.4921	24/84 (0.93)	No	0.5142	−88/91 (0.91)	0.4309
EHS	0.0001	18/90 (0.92)	No	0.5217	62/78 (0.71)	0.0130
LVS	0.3454	10/26 (0.83)	Yes	0.0001	−200/63 (0.89)	0.5426
LHS		5/30 (0.91)	Yes	0.0087	−175/72 (0.73)	
Redwood plywood (flat-grained)						
Smooth						
EVS	0.3782	71/100 (0.92)	Yes	0.0336	120/70 (0.79)	0.5646
EHS	0.0001	12/110 (0.92)	Yes	0.0073	228/60 (0.62)	0.8450
LVS	0.7079	22/29 (0.70)	No	0.0592	−215/66 (0.60)	0.3506
LHS		−6/31 (0.88)	No	0.3598	−100/47 (0.48)	
Saw-textured						
EVR	0.8127	158/80 (0.91)	No	0.6259	57/87 (0.86)	0.8190
EHR	0.0001	74/82 (0.93)	No	0.5860	−7/90 (0.85)	0.6172
LVR	0.0006	43/31 (0.95)	Yes	0.0001	−315/81 (0.96)	0.9399
LHR		69/18 (0.68)	Yes	0.0001	−267/81 (0.95)	
Douglas-fir lumber (vertical-grained)						
Smooth						
EVS	0.3025	14/73 (0.95)	No	0.3681	4/88 (0.77)	0.4124
EHS	0.0001	33/66 (0.91)	No	0.9891	145/66 (0.37)	0.0107
LVS	0.5857	19/22 (0.87)	—	0.1544	−115/41 (0.53)	0.6424
LHS		25/20 (0.87)	Yes	0.0023	−208/47 (0.81)	
Douglas-fir plywood (flat-grained)						
Smooth						
EVS	0.9106	63/52 (0.82)	No	0.4785	−158/65 (0.60)	0.5964
EHS	0.0001	70/51 (0.95)	No	0.8139	−51/55 (0.59)	0.1600
LVS	0.8150	25/19 (0.75)	Yes	0.0352	−144/41 (0.67)	0.7242
LHS		33/20 (0.96)	Yes	0.0450	−175/45 (0.61)	
Saw-textured						
EVR	0.6355	63/57 (0.86)	No	0.5812	142/50 (0.72)	0.1234
EHR	0.0001	116/53 (0.92)	—	0.1668	89/71 (0.80)	0.1847
LVR	0.1811	30/24 (0.84)	Yes	0.0883	−29/36 (0.78)	0.3116
LHR		80/18 (0.60)	Yes	0.0063	−60/46 (0.76)	

TABLE 3. *Continued*

	1 to 6 years		Rate change[b]		8 to 16 years	
Variable	P-value EV/EH EV/LV LV/LH	Erosion rate/year Yint/slope/R^2 (µm/µm/yr (%))	(Yes/no)	(P-value)	Erosion rate/year Yint/slope/R^2 (µm/µm/yr (%))	P-value EV/EH EV/LV LV/LH
		Southern Pine lumber (vertical-grained)[c]				
Smooth						
EVR	0.0010	4/69 (0.93)	—	0.0001	−1177/161 (0.74)	0.3836
EHR	0.0001	105/50 (0.85)	—	0.0013	−759/118 (0.66)	0.162
LVR	0.0137	14/31 (0.94)	—	0.1000	−243/48 (0.48)	0.7793
LHR		30/37 (0.95)	—	0.0099	−252/54 (0.82)	

[a] Y-intercept (Yint), slope, R^2, and significance for linear fit of data before and after joint point at 7 years of weathering for various wood species, surface textures, earlywood/latewood, and grain angles. P-values are from comparison of slopes of regression lines for measurements in years 1 to 6 and 8 to 16. Data show level of significance between EV and EH, EV and LV, and LV and LH. Certain values are boldfaced for emphasis (see text). EVS denotes earlywood, vertical, smooth; EHS, early wood, horizontal, smooth; LVS, latewood, vertical, smooth; LHS, latewood, horizontal, smooth. EVR denotes earlywood, vertical, rough (saw-textured); EHR, earlywood, horizontal, rough; etc.

[b] On the basis of the segmented regression, the 0–6-year slope was compared with the 8–16-year slope.

[c] For southern pine, linear regression was done for lines with a joint point at 12 years.

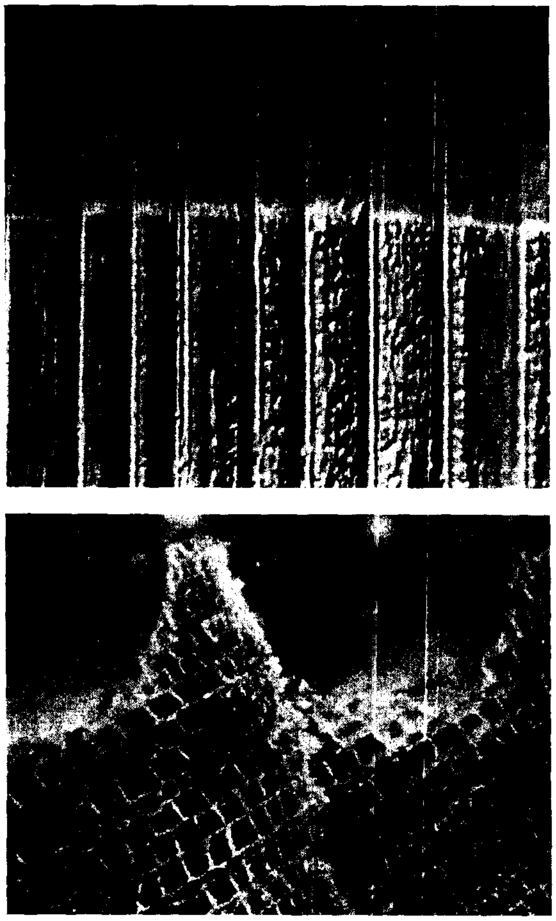

FIG. 9. Erosion of western redcedar. Top: weathered surface of wood; bottom: side view of a weathered surface showing differential erosion of earlywood and latewood.

The flat-grained plywood had both smooth and saw-textured surfaces. Although the differences between these surfaces were not great, the saw-textured surfaces of western redcedar and redwood plywood eroded faster than the smooth surfaces (Figs. 3 and 5). These differences were most obvious during the first 6 years of exposure. During this period, the erosion rate of western redcedar plywood was 131 µm/year for the smooth surface and 90 µm/year for the saw-textured surface (Table 3, EVS vs. EVR). For redwood, EVS was 100 µm/year and EVR 80 µm/year. Douglas-fir showed no notable difference between saw-textured and smooth surfaces.

During the 8- to 16-year period, the differences in erosion for different textured surfaces were rather inconsistent. For example, the erosion rate for western redcedar earlywood was about the same for both smooth and saw-textured surfaces (EVS and EHS = 68 and 65 µm/year, respectively; EVR and EHR = 64 and 61 µm/year, respectively) (Table 3). The erosion rate for western redcedar latewood was about 75 µm/year for smooth wood and 55 µm/year for saw-textured (LVS and LHS = 80 and 71 µm/year, respectively; LVR and LHR = 63 and 50 µm/year, respectively) (Table 3). We expected the saw-textured earlywood to erode slightly faster than the smooth earlywood because of surface damage from sawing.

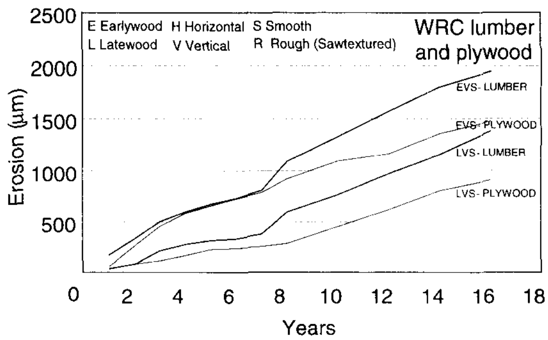

FIG. 10. Comparison of earlywood and latewood erosion rates of vertical-grained lumber and flat-grained plywood.

As occurred for the vertical-grained lumber, inspection of the erosion data for the flat-grained plywood surfaces revealed slightly more rapid erosion for vertically oriented fibers, particularly for smooth surfaces of western redcedar and redwood (EVS vs. EHS, LVS vs. LHS) (Figs. 3, 5, and 7). We speculate that this may have been caused by shading of the eroded earlywood by the latewood where the fibers were horizontal. The results for Douglas-fir were rather scattered and do not show this as clearly; there appears to be no difference for rough surfaces (EVR vs. EHR, LVR vs. LHR).

Lumber and plywood

Comparison of the erosion rates of smooth vertical-grained lumber with that of smooth flat-grained plywood showed considerable differences for some wood species. For example, the earlywood erosion rate of smooth vertical-grained western redcedar lumber was 109 µm/year (8–16-year exposure), whereas that of smooth flat-grained plywood was 68 µm/year (Table 3). This difference can easily be seen in Fig. 10. The difference between Douglas-fir and redwood erosion rates was not as great as that between these species and western redcedar. The greater difference in erosion of western redcedar was probably caused by fast earlywood erosion coupled with subsequent breaking of latewood bands. The flat-grained surfaces were less prone to show breakage of latewood bands.

Species differences

Typical erosion rates for lumber and plywood of different wood species are shown in Table 4. The rates listed for earlywood and latewood erosion were determined by averaging the values listed in Table 3 (8–16 years) for vertical/horizontal grain orientation and smooth/saw-textured surface, then arbitrarily rounding to the nearest 5 µm/year. For ease of

TABLE 4. *Typical erosion rates for various species and grain angles for 8–16 years outdoor exposure near Madison, Wisconsin.*[a]

Species, wood and orientation	Earlywood erosion[b] (µm/year)	Latewood erosion[b] (µm/year)	Avg erosion (µm) per year[c]	Erosion (mm) per 100 years
Western redcedar				
lumber, vertical	101.5	91.5	95	9.5
Plywood, flat	66.5	75.5	70	7.0[d]
Redwood				
Lumber, vertical	84.5	67.5	75	7.5
Plywood, flat	65.0	56.0	60	6.5[d]
Douglas-fir				
Lumber, vertical	77.0	44.0	60	6.0
Plywood, flat	60.0	43.0	50	5.0[d]
Southern pine				
Lumber, vertical	59.5	34.0	45	4.5[e]

[a] For southern pine, erosion rates were determined from slope of regression line from 0- to 12-year data.
[b] Average of erosion rates for vertical and horizontal (flat) grain exposures (EVS and EHS, LVS and LHS).
[c] Average of earlywood and latewood erosion rates rounded off to nearest 5 units.
[d] The face veneer would be gone long before 100 years had passed.
[e] Specimens were decayed after 12 years of exposure.

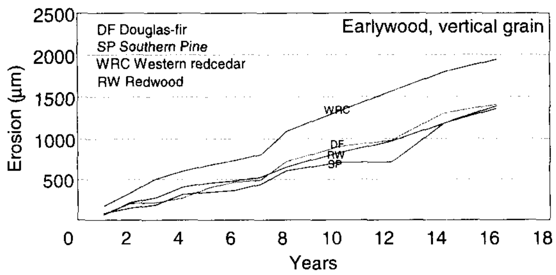

FIG. 11. Comparison of earlywood weathering of vertical-grained Douglas-fir, southern pine, western redcedar, and redwood lumber.

comparison, the erosion of earlywood (vertical orientation of longitudinal axis) for vertical-grained lumber is shown in Fig. 11. In general, softwood weathering has been reported to be about 6 mm/100 years; for western redcedar, erosion is about 12 mm/100 years (Feist and Mraz 1978). We found somewhat lower values for western redcedar, particularly for flat-grained surfaces.

CONCLUSIONS

For all wood species, erosion rates for earlywood and latewood differed greatly during the first 7 years of weathering. For Douglas-fir and southern pine, significant differences continued after 7 years. However, for western redcedar and redwood, erosion rates were generally about the same after 7 years. Erosion rates for vertical and horizontal grain orientations of the longitudinal specimen axis were only slightly different, which suggests that grain orientation might have a slight effect on the weathering of siding. We might expect slightly faster erosion of vertically oriented siding compared to horizontally oriented siding. The erosion rate of vertical-grained lumber was considerably higher than that of flat-grained plywood. Only slight differences were observed for saw-textured as opposed to smooth plywood. The erosion rates confirmed the effect of wood specific gravity, showing that more dense species weather more slowly. Erosion might also be affected by the growth rate of the wood, but we did not address this factor. The erosion rate for vertical-grained western redcedar was about 95 µm/year, slightly slower than previously reported.

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