# SURFACE CHARACTERIZATION OF WEATHERED WOOD USING A LASER SCANNING SYSTEM

*Martin Arnold*

Wood Technologist
Wood Section
Swiss Federal Laboratories for Materials Testing and Research
CH-8600 Duebendorf, Switzerland

*Richard L. Lemaster*

Research Leader, Nondestructive Evaluation/Process Monitoring
Forest Products Laboratory, University of California
Richmond, CA 94804

and

*William A. Dost*

Head, Wood Building Research Center
Forest Products Laboratory, University of California
Richmond, CA 94804

(Received December 1990)

ABSTRACT

Most of the existing methods to assess the effect of weathering on wood surfaces have some drawbacks that limit their use to specific tasks. The amount of surface erosion is often used as a measure for the weathering action. The application of a laser scanning system to reproduce surface profiles and to measure weathering erosion was tested on various samples and was found to be a very useful and superior alternative to existing methods. Further improvements of the system used can be made by refinements of the calibration procedures and by more comprehensive profile analyses.

*Keywords:* Laser scanning, surface profiles, weathering, wood surface erosion.

## INTRODUCTION

Quantification of the effect of weathering on wood surfaces has been the subject of study for a long time. The usefulness of weathering studies depends to a high degree on the accuracy and ease of measurement of the surface degradation due to the weathering. Most of the methods used have some drawbacks and are not applicable for general purpose studies, such as the determination of the influence of exposure, wood density, grain angle, etc. Thus, when conducting weathering studies, the search for more effective measuring methods is a primary objective.

The visual investigation of weathered wood surfaces—also with the help of microscopes—is probably the earliest and still most widely used method to study weathering effects on wood and finishes (Sell and Leukens 1971). It will give a good overall judgment of the surface condition, but requires a lot of rating experience. It also does not give a measurable value for the severity of surface degradation. Recording the weight loss of samples during weathering is occasionally used as a measurement for the degradation of the wood (Arndt and Willeitner 1969; Evans 1988; Williams 1988). However, maintaining a steady moisture content of the samples at the time of the measurements is difficult. The method is, also, not suitable for normal-sized samples, where the weight loss is only a small fraction of the

*Wood and Fiber Science,* 24(3), 1992, pp. 287–293

weight of the samples. Another way to study the effects of weathering is to measure the loss of tensile strength of thin wood strips (Raczkowski 1980; Derbyshire and Miller 1981). Again, this method is quite special and is limited to small sample sizes and therefore not suitable for practical tests.

The amount of surface erosion, measured as the depth of erosion on the earlywood and latewood bands, has proven to be a very good measure to assess the severity of weathering effects on unfinished wood (Feist and Mraz 1978; Sell and Feist 1986; Arnold et al. 1990). The rather laborious measurement ("Microscope Focusing" method) by recording the stage movement of a microscope between the focusing on the unweathered reference point and then refocusing on an adjacent point on the eroded part of the surface limits the number of practical readings.

For process control, several methods were developed to measure wood surface roughness and to describe surface texture (Pahlitzsch and Dziobek 1961; Peters and Cumming 1970; Bonac 1979; Faust and Rice 1986). One promising method for an adaption to erosion measurements was considered to be the stylus tracing system. With such a technique, one could obtain complete surface profiles and extract the desired erosion data. However, the sometimes deep eroded profiles of weathered wood surfaces make it difficult for the stylus tip to follow. On weathered surfaces, sudden and deep profile changes exist rather than just the gradual waviness and shallow roughness that are common in normal roughness measurements. Besides the slow tracing speed, a stylus will always give a somewhat distorted copy of the real profile because of the difficulties in following steep transitions and the effect of the radius of the stylus tip.

At the University of California, Forest Products Laboratory (UCB, FPL), a laser scanning system (LSS) has been used for several process control projects (Lemaster and Dornfeld 1982; Jouaneh et al. 1987; Yoo et al. 1988) and has been applied already to surface quality measurements. The particular objective of this study was to look into the possibilities and limitations of using a laser scanning system to reproduce and measure surface profiles of weathered wood.

## MATERIAL AND METHODS

The laser scanning system (Lemaster and Dornfeld 1982) used consists of a 2mW Helium-Neon laser and a single lateral effect photodiode mounted on a milling machine. The milling machine allows for accurate movement of the samples in the x and y direction using the table feed. The positional change of the reflected laser beam (from the sample surface) on a receiving photodiode is proportional to the vertical changes on the sample surface. The changes in the signal from the photodiode are collected digitally and stored in a computer. The speed of the milling table was set to 3.127 mm/s. With a sampling rate of 62.5 Hz, profile readings were taken every 0.05 mm of movement in the x direction. Because of the short time allowed for the study, the existing laser scanning system was used in the current setup and no further refinements were considered. Particularly the angles of incidence and reflectance of the laser beam remained at 45 and 70 degrees respectively, which was found to be optimum for surface roughness studies, but might be improved for special applications.

A change in the scanning mode, however, was necessary: Adopting the scanning mode of a stylus system, the samples were normally moved towards the incident laser beam, and thus were scanned perpendicular to the profile of interest. With strong structured surfaces to detect, this method will result in "shadowed" areas, where the laser beam cannot reach into every corner of the profile (Fig. 1a). Weathered boards offer a more or less uniform profile in the longitudinal (y) direction. By moving the samples with the profile of interest in front of the laser beam across, the scanning system is able to follow the rough profile in full (Fig. 1b). The scanning line is not a straight line any more, but because of the uniformity in the

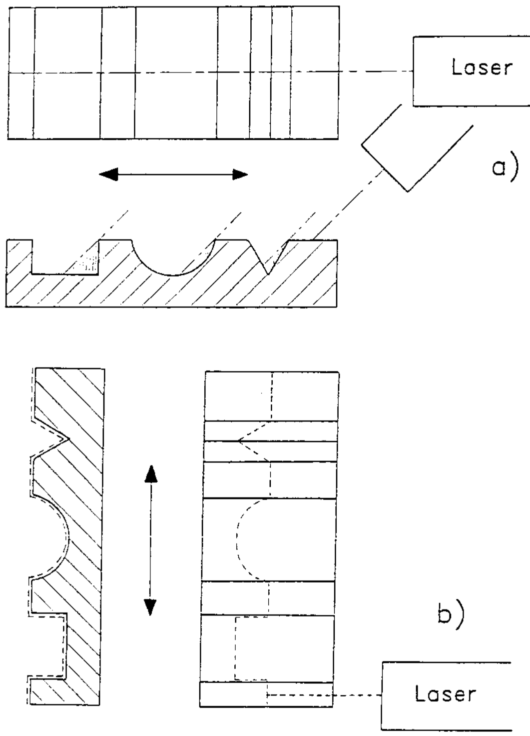


FIG. 1. Scanning methods: a) ordinary method with scanning perpendicular to the profile of interest, b) improved method with scanning along the profile of interest. The tracing path of the laser beam is given with dashed-dotted and dashed lines respectively.

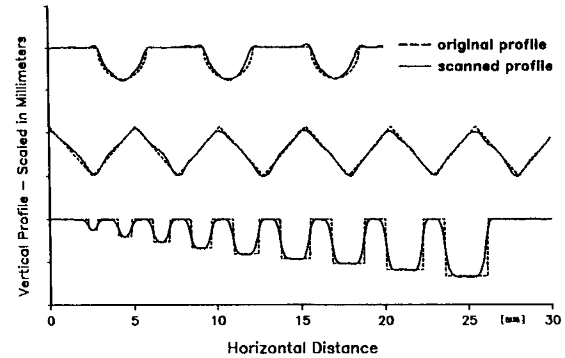


FIG. 2. Reproduction of three geometric profiles (Round, Triangle, Square).

longitudinal direction, the surface profile is still reproduced exactly (Fig. 2).

The work with the LSS was subdivided into three parts. First, the behavior of the system with respect to some wood characteristics was evaluated rather superficially. Also a calibration procedure was set up to translate the detector output to vertical profile changes in millimeters. Further, a set of geometric profiles cut into wood samples was scanned and the resulting profiles were compared with the original profiles. Second, a set of weathered wood samples for an earlier study (Arnold et al. 1990) was measured, and the calculated erosion parameters were compared with the readings by the "Microscope Focusing" method. Third, in an applied weathering study on redwood siding of different age and exposure, a casting method was used to take imprints of eroded boards. Measurements were made on these casts and analyzed further. Only earlywood erosion was analyzed. This was because the fragile eroded latewood bands were breaking away mechanically with increasing earlywood erosion and are of no use for the calculation of erosion rates any more. A detailed description of this study is published as a Technical Report at the UCB, FPL (Arnold and Dost 1990).

The profile analysis was done by either comparing two profiles point by point or by comparing extracted and calculated parameters. In the case of weathered wood profiles, three parameters are commonly used (Fig. 3), with earlywood erosion (EER) and latewood erosion (LER) best known. For this study the Peak-Valley-Distance (PVD), the distance between the highest point on the latewood and the deepest point on the earlywood of an individual growth ring, was chosen as the parameter for the comparison. This was mainly because of the ease in which the parameter could be reliably measured with the alternative "Microscope Focusing" method. Compared to the earlywood or latewood erosion, the PVD does not depend on a sometimes uncertain reference point on the unweathered part of the sample. The PVD can also be extracted easily from the data of the scanned profile by searching for the maximum and minimum within the selected growth rings. Twenty PVD's on five growth rings per sample were compared on four species with two replications each. The

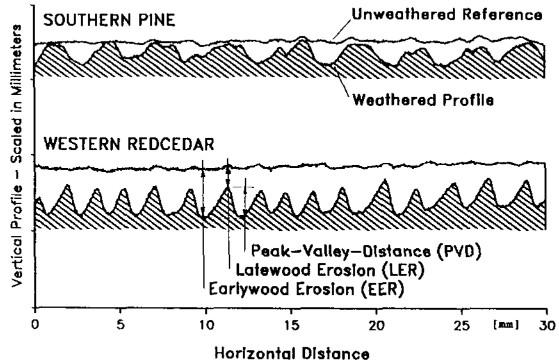


FIG. 3. Scanned surface profiles of wood after 2400 h of accelerated weathering with usual erosion parameters. The different characteristic of the wood species is apparent.

results are given in figures and tables and show the deviation from the alternatively measured profiles and values. Mainly, the results are intended to give an idea of the accuracy of the existing system.

## RESULTS AND DISCUSSION

While working on the calibration procedure, it soon became obvious that the calibration had to be done for each species individually. There is a linear relationship between the detector readings and a vertical displacement on the sample surface within a range of 3–4 mm. The slope of this curve, however, changes with the sample material. The differences of the species are due mainly to the different colors. They affect the reflectance of the laser light the most of all the factors investigated. The darker the sample surface, the less light that is reflected into the detector device. There is also some influence of the grain direction. This is sometimes combined with color effects: There is a considerable difference in output between the earlywood and the latewood bands on end-grained wood, while this difference fortunately can be neglected on the vertical-grained wood on our weathering samples. Cracks on the sample surface and sharp edges (eroded latewood on some species) also affect the reflectance. If the incident laser beam is being trapped (cracks) or completely dispersed (sharp edges), not enough light is reflected into the detector to give a reliable reading. These effects can be monitored by not only recording the position of the reflected laser beam on the photodiode but by also measuring the intensity of the reflected light.

The laser scanned geometric profiles show a very good reproduction of the original profiles (Fig. 2). The average vertical deviations from the original profiles are small (Table 1) and are in the range of the possible resolution of the entire system. The largest deviations are around the steep transitions of the profiles, especially on the square profile. This is due to the dimension of the laser light spot on the sample surface, which is about 1 mm in diameter. With its center on the edge of the square-shaped groove, half of the light is still reflected from the top surface, while the other half is reaching the bottom of the groove. This results in a smoothing of the transition. Still the reproduction of the square profile is quite good and took only 10 seconds to scan with the given feed speed. The reproducibility of the scanning system can be shown with two repeated scans on a weathered surface of western redcedar (Fig. 3) in reverse direction. The deviations never exceed 5/100 of a millimeter (Table 2).

With the weathered wood samples, the results of the comparison of twenty PVD readings per sample with the two methods are different for the wood species (Table 3). Some caution must be noted for this comparison be-

TABLE 1. *Accuracy of reproduction of geometric profiles.*

| Profile | Scanning length (mm) | Number of data points | Vertical deviation from original profile (mm) | | | | |
|---|---|---|---|---|---|---|---|
| | | | x | s | Range | | |
| Round | 20 | 400 | 0.09 | 0.127 | −0.09 | – | +0.54 |
| Triangle | 30 | 600 | −0.01 | 0.096 | −0.26 | – | +0.26 |
| Square | 30 | 600 | 0.01 | 0.299 | −1.17 | – | +1.98 |

TABLE 2. *Reproducibility of measurements shown with two repeated scans in reverse feed direction.*

| Profile | Scanning length (mm) | Number of data points | Vertical deviation from original profile (mm) | | | | |
|---|---|---|---|---|---|---|---|
| | | | x | s | Range | | |
| Weathered western redcedar | 60 | 1,200 | −0.004 | 0.014 | −0.053 | — | +0.044 |

TABLE 3. *Comparison of profiles measured with LSS and "Microscope Focusing" method.*

| Species | Sample | Number of measurements | Comparison of Peak-Valley-Distance (PVD) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | r | Vertical difference between LSS and "Microscope Focusing" readings (mm) | | | | |
| | | | | x | s | Range | | |
| European Yew | 1 | 20 | 0.67 | −0.018 | 0.016 | −0.056 | — | +0.018 |
| | 2 | 20 | 0.61 | −0.010 | 0.022 | −0.048 | — | +0.025 |
| European Spruce | 1 | 20 | 0.82 | −0.039 | 0.039 | −0.115 | — | +0.032 |
| | 2 | 20 | 0.93 | 0.025 | 0.034 | −0.029 | — | +0.084 |
| Southern Pine | 1 | 20 | 0.46 | 0.048 | 0.084 | −0.112 | — | +0.178 |
| | 2 | 20 | 0.81 | 0.184 | 0.077 | +0.062 | — | +0.335 |
| Western Redcedar | 1 | 20 | 0.91 | −0.051 | 0.073 | −0.204 | — | +0.035 |
| | 2 | 20 | 0.96 | −0.070 | 0.050 | −0.163 | — | +0.034 |

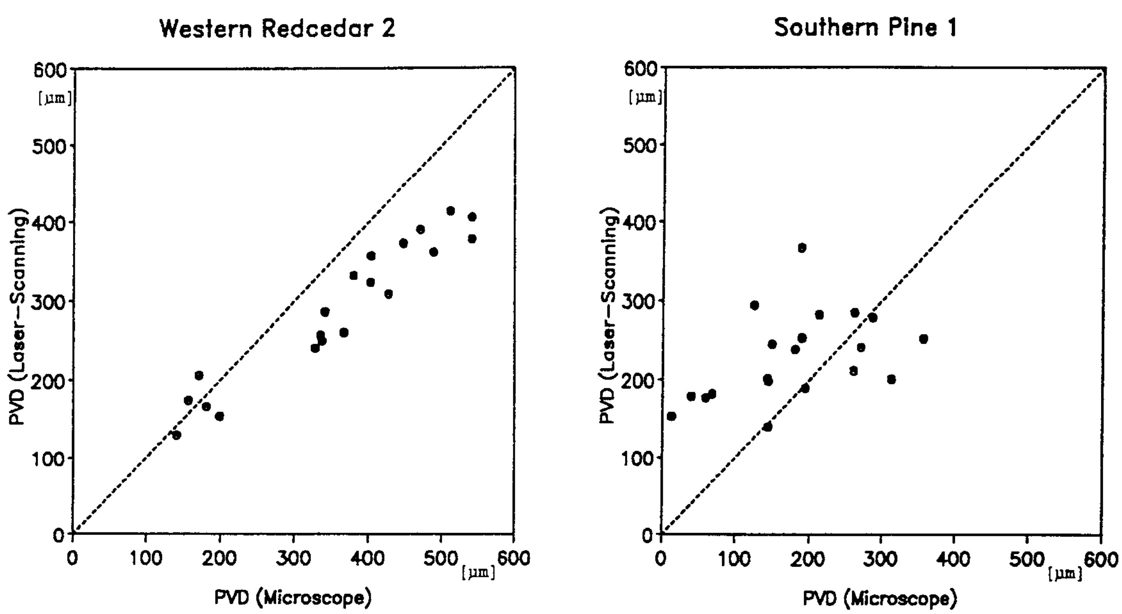


FIG. 4. Comparison of the erosion parameter PVD (Peak-Valley-Distance) measured with the laser scanning system and the conventional "Microscope Focusing" method (See also Table 3). Two examples: western redcedar shows good correlation ($r = 0.96$), while with southern pine the parameters are correlated rather loose ($r = 0.46$). The dashed line indicates the line of perfect match.

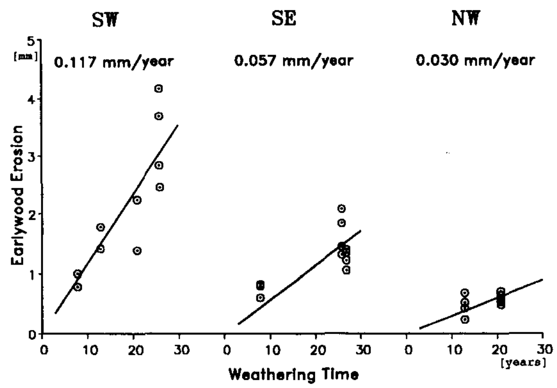


FIG. 5. Erosion rates on redwood siding for different exposure directions at the University of California, Forest Products Laboratory, Richmond, CA.

cause the readings from the "Microscope Focusing" method are also not free of error. The general results appear clear. With European yew the absolute differences are small. The coefficients of correlation (r) are rather low because with this dense wood species even the small errors are substantial compared to the small erosion values. European spruce can be measured reliably, whereas southern pine exhibits possible errors up to 1/10 of a millimeter. High coefficients of correlation and average absolute differences were found with western redcedar. Figure 4 shows two extreme examples: western redcedar has a close relationship between the readings of the two methods due to its uniform structure and color. The deviations from the indicated line of perfect match are indicative of problems related to the calibration. Southern pine shows a rather loose relationship. The heavily cracked surface and the different characteristics of the earlywood and latewood bands (color) may account for this problem.

The practical application of this new measuring technique on the weathered redwood siding of buildings at the UCB, FPL confirms the important influence of exposure conditions in the erosion of the wood (Fig. 5). Boards on walls facing south and west are generally most exposed to sunshine and rain and therefore have the deepest surface erosion. The erosion rate for the SW exposure (0.117 mm/year) is almost as high as an often used rule of thumb (Feist and Mraz 1978), which expects 0.5 inches erosion within 100 years (0.127 mm/year) for western redcedar. Compared with other known erosion data, these erosion rates indicate a rather high weathering stress in the climate of the San Francisco Bay Area.

## CONCLUSIONS

The application of the laser scanning system is certainly a good alternative to other available methods to assess the erosion of wood due to weathering. With its ability to collect significantly more erosion data in a shorter period of time than is practical with other methods, this new approach can give better average erosion values, in spite of some small errors in the individual readings. With the reproduction of entire surface profiles, this method gives very comprehensive information about surface conditions. Commercial laser-based scanning equipment and computer-based x-y feed systems are available that could be used to assemble a system similar to the one used in this study. The sampling method with casted replicas of the eroded wood surface offers the possibility of collecting large amounts of information contained in the siding and roofing of countless buildings concerning the weathering of wood.

The calibration should be improved, especially with regard to the differences of the wood species and anatomical changes within the samples. The best method so far is to provide a calibration curve for each sample at the time of the measurement. Another area of future work should be the analysis of the recorded surface profiles. New erosion parameters besides the depth of erosion may lead to a better use of the information contained in the profile data and may show new evidence for weathering processes.

## ACKNOWLEDGMENT

The senior author was a visiting scientist at the Forest Products Laboratory, University of California, and wishes to express his gratitude for the opportunity and support of this study. The assistance and help of the staff of the FPL are gratefully acknowledged.

## REFERENCES

ARNDT, U., AND H. WILLEITNER. 1969. On the resistance behavior of wood in natural weathering. Holz Roh-Werkst. 27(5):179–188.

ARNOLD, M., AND W. A. DOST. 1990. Weathering erosion of redwood siding on vertical walls with different age and exposure. Technical Report No. 35.04.187, University of California, Berkeley, Forest Products Laboratory.

———, J. SELL, AND W. C. FEIST. 1990. Accelerated weathering of wood in fluorescent ultraviolet light and xenon arc chambers using a water spray. Forest Products Journal (in press).

BONAC, T. 1979. Wood roughness volume and depth estimated from pneumatic surface measurements. Wood Science 11(4):227–232.

DERBYSHIRE, H., AND E. R. MILLER. 1981. The photodegradation of wood during solar irradiation. Part I: Effects on the structural integrity of thin wood strips. Holz Roh-Werkst. 39:3341–3350.

EVANS, P. D. 1988. A note on assessing the deterioration of thin wood veneers during weathering. Wood Fiber Sci. 20(4):487–492.

FAUST, T. D., AND J. T. RICE. 1986. Characterizing the roughness of southern pine veneer surfaces. Forest Prod. J. 36(3):57–60.

FEIST, W. C., AND E. A. MRAZ. 1978. Comparison of outdoor and accelerated weathering of unprotected softwoods. Forest Prod. J. 28(3):38–43.

JOUANEH, M., R. L. LEMASTER, AND D. A. DORNFELD. 1987. Measuring workpiece dimensions using a non-contact laser detector system. Intl. J. Advanced Mfg. Technol. 2(1):59–74.

LEMASTER, R. L., AND D. A. DORNFELD. 1982. Measurement of surface quality of sawn and planed surfaces with a laser. Pages 54–61 *in* Proceedings of 7th Wood Machining Seminar, University of California, Forest Products Laboratory.

PAHLITZSCH, G., AND K. DZIOBEK. 1961. Beitrag zur Bestimmung der Oberflaechenguete spanend bearbeiteter Hoelzer. Erste Mitteilung: Messverfahren und Beurteilungs-methoden fuer bandgeschliffene Hoelzer. Holz Roh-Werkst. 19(10):403–417.

PETERS, C. C., AND J. D. CUMMING. 1970. Measuring wood surface smoothness: A review. Forest Prod. J. 20(12): 40–43.

RACZKOWSKI, J. 1980. Seasonal effects on the atmospheric corrosion of spruce micro-sections. Holz Roh-Werkst. 38:231–234.

SELL, J., AND W. C. FEIST. 1986. Role of density in the erosion of wood during weathering. Forest Prod. J. 36(3): 67–60.

———, AND U. LEUKENS. 1971. Investigations on weathered wood surfaces. Part 2.: Weathering phenomena of unprotected wood species. Holz Roh-Werkst. 29(1):23–31.

WILLIAMS, R. S. 1989. Effect of dilute acid on the accelerated weathering of wood. JAPCA 38(2):148–151.

YOO, S. M., D. A. DORNFELD, AND R. L. LEMASTER. 1988. Analysis and modeling of laser measurement system performance for wood surfaces. Transactions of the American Society of Mechanical Engineers. ASME J. Eng. for Industry 112(1):69–77.