Using NIR Spectroscopy to Predict Weathered Wood Exposure Times

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Summary

This poster presentation reports on recent laboratory work aimed at quantifying the biodegradation process of wood during exposure to natural weathering. Approximately 330 southern pine lumber specimens were placed "above-ground" at an outdoor exposure site near Gulfport, Mississippi for periods up to five years. An additional 90 specimens were stored indoor to serve as controls. Two chemical preservative treatments, CCA and DDAC, were also applied to several sets of lumber specimens. NIR spectroscopy techniques were used to characterize the condition of the weathered wood surface. Multivariate statistical tools were used to further analyze NIR spectra data. Results indicate that NIR spectra analysis, in conjunction with multivariate statistical analysis, has good potential for monitoring changing surface conditions of wood structural members subjected to natural weathering.

1. Introduction

Estimating the residual strength of structural members is an important tool for inspection professionals. For timber structures, several techniques have been successfully used to detect and map interior decay or defect pockets [1]. However, few techniques have been studied that provide a good indication of the residual strength of structural timbers. Quantitative techniques that can provide an indication of the weathered member strength are needed by engineers in order to more reliably predict a safe service-load capacity for timber structures.

One evaluation tool with good potential is near-infrared (NIR) spectroscopy, a fast growing technique for nondestructively evaluating organic materials. NIR spectroscopy has found widespread use in variety of industries including food and agriculture, pharmaceutical, petroleum, and pulp and paper. NIR spectroscopy involves the measurement of the wavelength and intensity of the absorption of near-infrared light by a specific material. NIR spectroscopy is a promising candidate for monitoring change in lumber surface characteristics due to natural weathering. The objective of this research study was to characterize surface characteristics of preservative-treated southern pine specimens using near-infrared spectroscopy equipment at various natural exposure levels.

2. Materials and Methods

2.1 Material preparation

Nominal 51x102 mm specimens, 31cm long southern pine specimens were pre-conditioned to a moisture content of 12 percent. The specimens included three types of materials: untreated wood, CCA treated wood, and DDAC treated wood. Treated specimens were re-dried to 16 percent moisture content after treatment. A total number of 420 specimens were selected for this study, including 180 untreated specimens, 90 CCA (chromated copper arsenate) treated specimens, and 150 DDAC (didecyl dimethyl ammonium chloride) treated specimens (Table 1).

Table 1 – Weathering intervals and preservative retentions.

Weather exposure (months)	Controls		CCA treated		DDAC treated	
	Retention (kg/m^3)	# tested	Retention (kg/m^3)	# tested	Retention (kg/m^3)	# tested
0	--	30	6.41	30	4.81	30
12	--	30				
24	--	30				
36	--	30			4.81	30
48	--	30				
60	--	30	3.20	30	2.40	30
			6.41	30	4.81	30
					9.61	30

2.2 Field Exposure

61 cm long southern pine specimens were exposed to natural weathering at the USDA Forest Service, Harrison Experimental Forest located in Saucier, Mississippi. Southern pine specimens were exposed in a clearing within a pine forest, which received partial shading during the course of the day. The specimens were randomly placed on racks approximately 1 meter above ground. The boards were subjected to different periods of exposure conditions (0, 12, 24, 36, 48, 60 months) and each group of exposure time contained 30 individual specimens. Although 62 cm long specimens were originally exposed to weathering, only one-half (approximately 31 cm long), southern pine specimens were evaluated in this study. After field exposure, all specimens were stored indoors at approximately 12 percent moisture content for several years prior to testing.

2.3 NIR Spectroscopy

NIR measurements were conducted with a LabSpec Pro NIR spectrophotometer (Analytical Spectral Devices, Inc.) at wavelengths between 350nm and 2,500nm. Spectra were collected at four equally spaced locations along the center line of weathered surface for each specimen. Ten scans were collected and averaged into a single average spectrum from each location. The four averaged spectra collected on each specimen were also averaged to provide a single spectrum that was then used for further analysis. The data set was further reduced by averaging the spectra that were collected at 1 nm intervals, to a spectra data set at 5 nm intervals. Multiplicative Scatter Correction (MSC), a transformation method used to compensate for additive and /or multiplicative effects in spectral data, was applied to each exposure group separately.

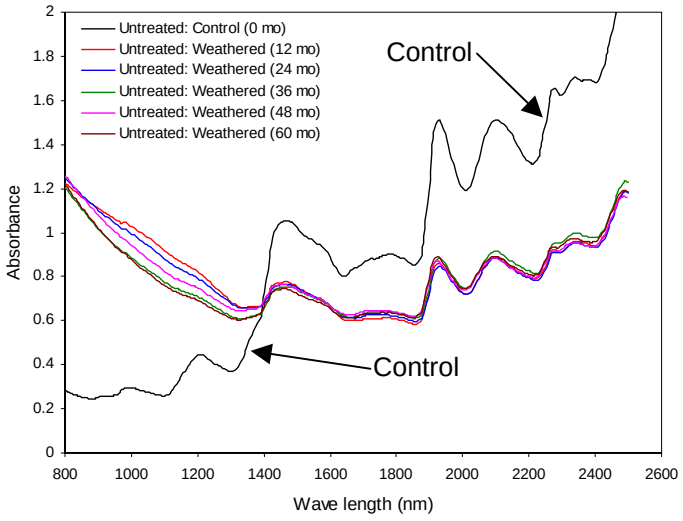

Fig 1. Average NIR spectra of control wood (un-weathered) and the wood exposed to weather for different periods of time (untreated southern pine specimens).

2.4 Multivariate Analysis

The spectra collected on each sample were averaged to provide a single spectrum for principal component analysis (PCA) and projection to latent structures (PLS) modeling. Multivariate analysis was performed using the Unscrambler (CAMO, Corvallis, OR, USA). All of the NIR spectra were combined into a single data matrix (X-matrix) while the weathering exposure time constituted the response matrix (Y-matrix). The X-matrix was mean centered variance normalized prior to performing the multivariate analysis. Calibration models (CALB) were constructed with about two thirds of the samples using full cross-validation. The model was then used to predict the response of the test set (TEST) that contains about one third of the samples that were not included in the original model. This conservative approach insures that the predictive capabilities of the model are reliable.

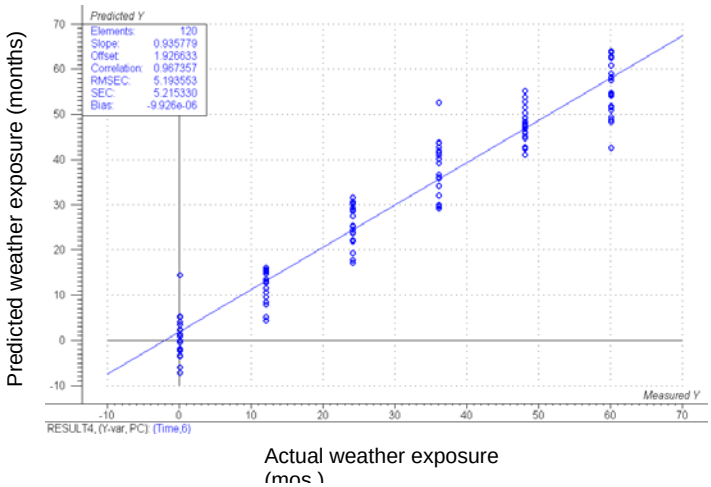

Fig 2. Relationship between the actual exposure time and the NIR-predicted weathering time (PLS model – Calibration).

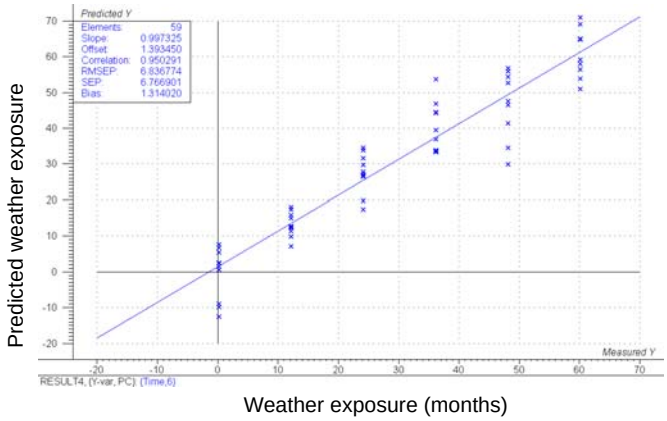

Fig 3. Relationship between actual exposure time and NIR-predicted weathering time (PLS model - TEST).

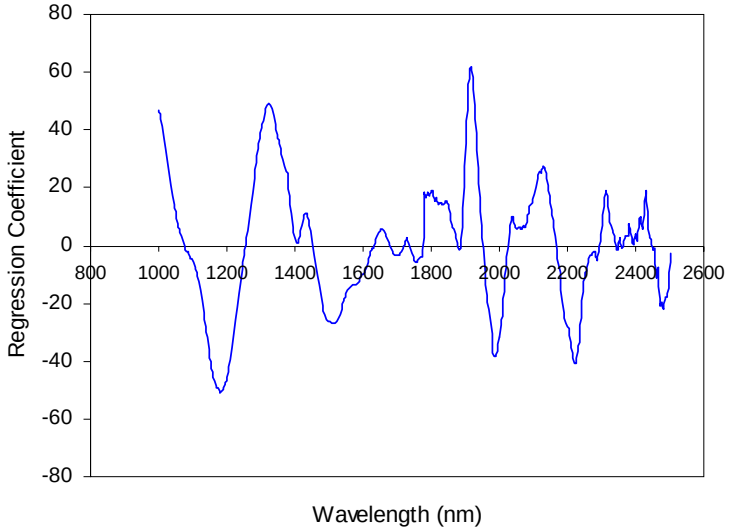

Fig. 4. Regression coefficients for the PLS model correlation between NIR spectra and exposure time.

3. Results

3.1. NIR Data for Untreated Wood

Figure 1 shows the averaged NIR spectra of the control wood (unweathered), and the wood exposed to weather for different periods of time. It is noted that the differences between weathered and unweathered wood are clear in both absorbance intensity and shape of the spectra bands. This is reflected at the lower wavelength ranges (<1400 nm). The raw spectra of weathered wood indicted that prolonged natural weathering is a phenomenon affecting all wood compounds [2]. In general, the major peaks (>1400 nm) for weathered wood are greatly reduced due to a loss of wood compounds. If decay is also present, physical and mechanical properties of the bulk material will be affected, as decay fungi are able to cause rapid strength losses in wood associated with a loss of weight.Using the exposure time of natural weathering and the NIR spectra collected on the untreated southern pine specimens, a PLS model was constructed. The following result is based on PLS-2 model that predict weathering duration (exposure time) from measured NIR spectra. The model was constructed using the spectral range of 1000 – 2500 nm and spectra that were averaged over 5 nm interval. The results of both the CALB and TEST models for actual exposure time vs. predicted exposure time are shown in Figure 2 and Figure 3. These results show a very strong correlation between the actual exposure time and the predicted weathering time as shown by the regression coefficients in Figure 4. These NIR spectral vibrations are strongly correlated with natural degradation in weathered wood. NIR is particularly sensitive to subtle differences associated with hydrogen bonding in wood, and the differences between carbohydrate and lignin hydroxyls [3], which might be impacted by the natural weathering process.

The strong correlation coefficient between predicted and actual exposure time indicates that the NIR spectra are very sensitive to changes in the wood structure that are associated with degradation in weathered wood.

4. Concluding Remarks

The data indicates that NIR spectra analysis, in conjunction with multivariate statistical analysis, has good potential for monitoring changing surface conditions of wood structural members subjected to natural weathering.

5. Future Research

In addition to the NIR spectra, additional data sets using other inspection techniques are being conducted using these naturally weathered specimens. The planned tests include stress wave ultrasonic measurements (transverse and longitudinal to grain orientation), hardness strength, screw withdrawal strength, and resistance micro-drilling. In order to relate the NIR and other data sets directly to strength losses associated with weathering effects, static bending tests will be conducted on interior portions of the southern pine lumber specimens.

Models will be developed that will relate the relative loss of strength, as determined by the ratio of the MOR at given time divided by the initial MOR, to combinations of inspection techniques. In addition, multivariate statistical analysis will also be used to determine if changes in preservative chemicals can be monitored using NIR spectroscopy.

6. References

[1] Ross, R.J., X. Wang, and B.K. Brashaw. 2005. *Inspection and Monitoring Techniques for Bridges and Civil Structures – Chapter 4.3 Decay Detection*. Woodhead Publishing Limited. Cambridge, England.

[2] Anderson, E.L., Z. Pawlak, N.L. Owen, and W.C. Feist. 1991. Infrared studies of wood weathering. Part I: Softwoods. Applied Spectroscopy, 45(4): 641-647.

[3] Kelly, S.S., J.Jellison, and B. Goodell. 2002. Use of NIR and pyrolysis-MBMS coupled with multivariate analysis for detecting the chemical changes associated with brown-rot biodegradation of spruce wood. FEMS Microbiology Letters 209 (2002): 107-111.

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