Near infrared evaluation of coated wooden surfaces exposed to natural weathering

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Introduction

Wood is a biological material that is degraded by various environmental agents. Coating the surface of wood is a method commonly used for increasing natural durability and several coating products are available. However, the performance of such products varies with brand, colour and wood species.

Near infrared (NIR) spectroscopy has been successfully used to predict the natural durability and resistance of wood,[1] for distinguishing preservative types and retention time,[2,3] and for monitoring wood modifications caused by light irradiation and heat treatment.[4] Additional NIR research has focused on the recognition of wood species.[5-7] The main goal for the work presented here was to provide a better understanding of the physico-chemical changes that occur in wood during natural weathering. More specifically, our aim was to evaluate whether NIR could provide valuable information with regard to weathering and consequently assist in the selection of the proper coatings.

Materials and Methods

Twenty different wood species have been used as experimental samples. Species included eight softwoods: *Picea abies* (1 sample), *Tsuga* sp. (2), *Abies alba* (3), *Pinus ponderosa* (4), *Pinus cembra* (5), *Larix* sp. (6), *Pinus silvestris* (7), *Thuja plicata* (8); three domestic hardwoods: *Quercus* sp. (9), *Robinia pseudoacacia* (10), *Castanea sativa* (11); and nine exotic wood species: *Chlorophora exelsa* (12), *Tectona* sp. (13), *Pericopsis elata* (14), *Milletia laurentii* (15), *Entandrophragma utile* (16), *Aucoumea klaineana* (17), *Lophira alata* (18), *Arariba* sp. (19), *Shorea laevifolia* (20). Selected samples were coated with 21 materials provided by several producers. The coatings included products based on water/acrylic resin, water/alkyd resin, water/neutral resin, water/acrylic-alkyd resin, organic/alkyd resin, organic/oil resin. Samples were exposed to natural weathering for four years on a field stand as presented in Figure 1. Non-coated wood samples were also weathered for reference purposes.

Figure 1. Field stand for holding experimental samples during natural weathering test.

Each sample was measured six times (subsequent to coating and after 0.5, 1, 2, 3 and 4 years of exposure). Five spectra were scanned from the sample surface each time and averaged. Spectra were collected with a Vector 22n NIR spectrometer (Bruker Optics GmBH, Ettlingen, Germany), equipped with a standard fibre-optic probe. Each spectrum was an average of 32 scans measured across 4000–12000 cm^{-1} with a spectral resolution of 8 cm^{-1}; spectra were collected at 20°C and 60% relative humidity. Wood samples were conditioned for two weeks in a climatic chamber before measurement (to achieve an equilibrium moisture content of ~12%) to minimise any effect of moisture variations on NIR spectra. Spectra

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were analysed using hierarchical clustering and principal component analyses and 2D spectral correlation (within OPUS 6.5).

Results and Discussion

NIR spectra collected from non-coated wood separated into two clusters - softwoods and hardwoods (Figure 2). The hardwood cluster was subdivided according to the provenance of samples; European species were placed in one minor sub-cluster and exotic woods covered the second group. All samples were correctly discriminated into proper classes and no species was misclassified.

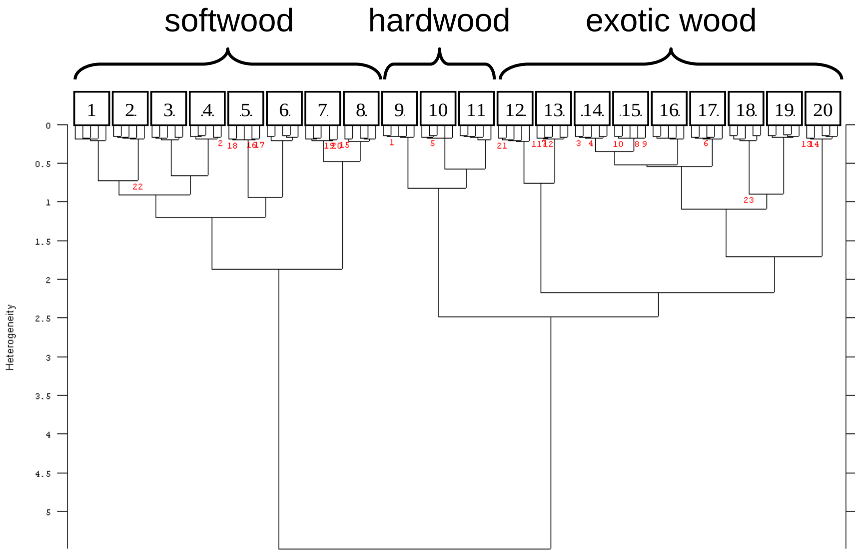

Figure 2. Recognition of wood species by means of NIR spectroscopy and cluster analysis.

Figure 3 presents principal component score values from the spectra of 6 different types of coatings. Spectra were grouped according to varnish type, even though the coatings were provided by different producers. Weathering-induced spectral changes varied with finish type. Substantial changes occurred for water/acrylic-coated surfaces whereas few differences were noticed for organic/alkyd surfaces.

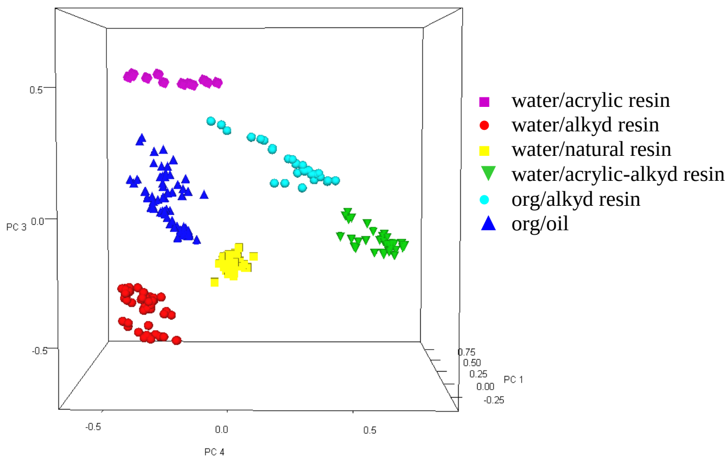

Figure 3. Identification of coatings applied on wood by principal components analysis on NIR spectra (4200–10000 cm^{-1}, 2nd derivative + vector normalisation, 5 smoothing points, 2 factors).

The effect of weathering on the spectra of natural wood is shown in Figure 4. Indeed, substantial spectral changes occurred after only two years of exposure with nearly all functional groups showing variation. The most significant changes were observed in regions attributed to the aromatic skeleton of lignin (5980 cm^{-1}) and the hemicelluloses (5800 cm^{-1}).

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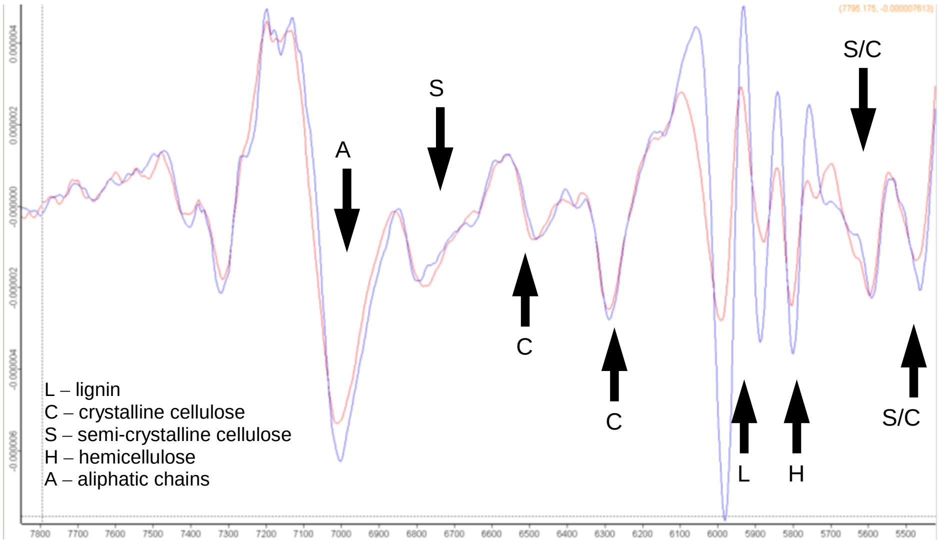

Figure 4. Changes to functional groups in red cedar (*Thuja plicata*) wood exposed to natural weathering for two years.

Figure 5 presents the progression of spectral change during the four years of exposure. Although progress was continuous, the most significant changes took place in first year of weathering. By analogy to the results of the red cedar, the chemical components most affected in spruce wood were lignin and hemicelluloses.

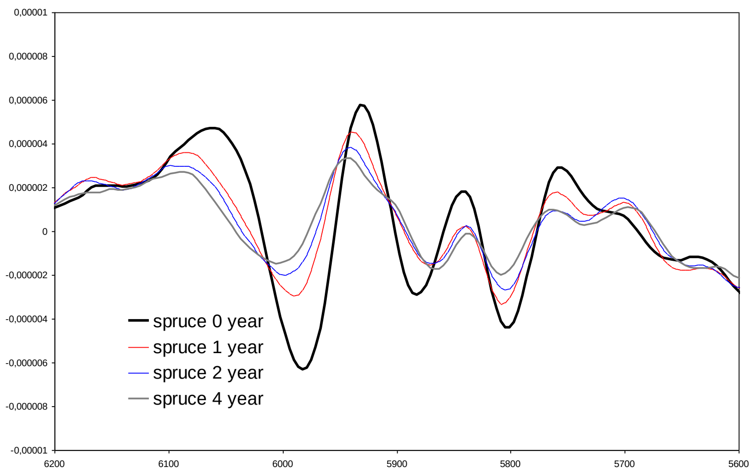

Figure 5. Changes to the NIR spectra of non-coated spruce (*Picea abies*) wood due to natural weathering over time.

2D spectral correlation was used to assess wood spectral changes due to weathering, with weathering time as the disturbance. The resulting synchronous and asynchronous charts show that several spectral regions changed over time (Figure 6). The highest peak can be attributed to water which suggests that the hygroscopic properties of wood changed after weathering. 2D spectral correlation graphs are thus useful for understanding of the mechanisms of wood degradation due to natural weathering.

Conclusion

NIR spectroscopy was successfully used to monitor the weathering process of both coated and non-coated woods and to quantify the chemical degradation of various finishing products. Clusters and identity tests clearly separated spectra of fresh and weathered surfaces. Indeed, more resistant coatings presented a much smaller heterogeneity. 2D spectral correlation revealed those functional groups mostly affected by weathering.

Studying the changes in NIR spectra has helped to understand the dynamic between weathering, wood species and coating type resistance.

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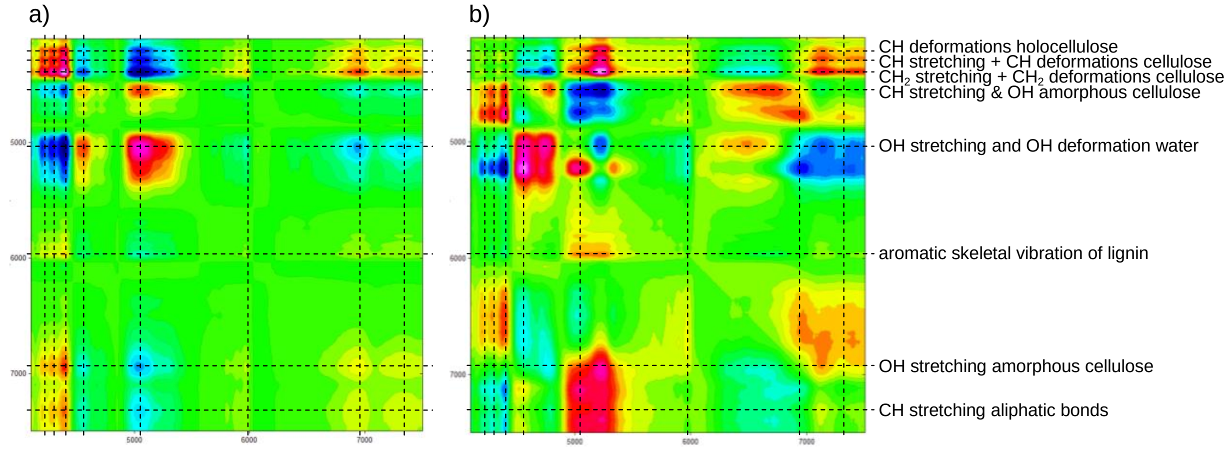

Figure 6. 2D spectral correlation, synchronous (a) and asynchronous (b) for NIR spectra of non-coated spruce (*Picea abies*) wood exposed to natural weathering.

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