Novel non-destructive methods for wood

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Abstract

The variation of wood properties has a high impact on the quality of wood. Thus, it would be important to determine the material properties of wood to optimize its use. Nowadays, sampling and destructive testing methods are frequently needed to investigate the wood properties. One of the potential methods for non-destructive analysis of wood is electrical impedance spectroscopy (EIS). The EIS method uses relatively low frequency electromagnetic waves including spectral and model analyses to enhance the evaluation. Studied EIS applications included moisture content, moisture gradient, decay, density and extractive analyses. The electromagnetic spectrum analyses include also studies using rf-, microwave and IR techniques for evaluating wood properties. Acoustic emission technique has been studied especially for monitoring wood drying. A method based on combined electrical and acoustic emission method has been developed to optimise wood drying. Ultrasonic technique has been applied e.g. for thermally modified wood and veneer analyses. Also, air-coupled ultrasonic techniques have been recently studied. Gamma ray attenuation technique was used to monitor moisture and density distributions in wood samples. The overall goal was to examine the relations between wood properties and defects with the NDE responses for developing novel methods to improve the assessment of wood.

1 Electrical impedance spectroscopy studies

Electrical impedance spectroscopy (EIS) is quite a novel method for characterising and imaging the electrical properties of materials (MacDonald 1987). EIS may be used to investigate the dynamics of bound or mobile charge in the bulk or interfacial regions of liquid or solid materials (e.g. ionic or insulator materials). Electrodes are used to introduce a changing electric field into the material and the spectral responses are measured. In EIS, the complex electrical impedance is measured at number of frequencies to obtain a frequency spectrum. The measured impedance consists of a real part (resistance R) and an imaginary part (reactance X). Electrical model analyses are used to study the electrode-material interface and the material. In impedance spectroscopy analysis, the changes in concentrations of charge carriers and the effect of changing microstructure are compared with impedance responses, and different types of electrical models are studied for describing the effect. An emphasis is typically put on the models with distributed elements which can be used for estimation of different types of resistance and capacitance distributions.

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A new EIS-method and equipment (Fig.1) were developed to permit the evaluation of the wood moisture gradient (Tiitta and Olkkonen 2002). The method uses one-sided parallel plate surface electrodes and it is based on the dispersive characteristics of wood. Electrical modelling including spectral parameters could be effectively used for moisture gradient analysis. Changes due to soft-rot decay and the physical and chemical properties were examined using EIS analyses from small specimens using a through-transmission technique (Tiitta et al. 2001). When EIS analyses of decayed specimens at low MC were conducted, it was found that the presence of decay changes the electrical properties of wood. This effect could be analysed using the model analysis. Also a comparison was made between the effects of physical properties (density, moisture and water content) and chemical properties (extractives). The effect of the different properties could be distinguished by the electrical model parameter analysis (Tiitta et al. 2003). It was shown that EIS could be used effectively for the wood analyses.

Figure 1. EIS equipment applied for the measurement of round wood.

2 Electromagnetic studies using higher frequencies

Dielectric properties of Scots pine were compared with the density, moisture content, and the resin acid content of heartwood (Tomppo et al. 2009). The samples were measured in frozen, green, conditioned and unconditioned dry moisture state to find out the potential of dielectric spectroscopy to determine the wood characteristics at different stages of wood processing. Heartwood and sapwood part of each sample was measured separately and through-transmission measurement was conducted in longitudinal and tangential direction at frequencies from 1 MHz to 1 GHz. As assumed, the moisture content and density correlated significantly with the dielectric parameters in both measurement directions but especially in longitudinal direction. For the resin acid content of the heartwood, there were significant correlations with $\tan \delta$ and

$\varepsilon''/(\varepsilon' - 1)$ of the green samples measured in tangential direction at frequencies above 200 MHz.

3 Combined Acoustic emission and EIS technique

Acoustic emission (AE) is defined as the spontaneous release of localized strain energy in a stressed material (Beall 2002). AE can be sensed with piezoelectric transducers coupled physically to the surface of the material and the method is useful especially for the investigation of local damage in materials. Wave pattern recognition analyses have been widely used in AE. With the AE method, cracking of wood can be measured quantitatively even before any visible macro-cracks appear in the wood (Beall 2002, Tiitta et al. 2007). The emissions generated by the cracks are proportional to the stresses appearing inside the wood.

The combined method is based on using electrical method for moisture gradient monitoring and acoustic emission method for detection of micro-cracking. In the method, electrodes are used to create electric field in drying wood and measure the electric complex spectrum using the impedance spectroscopy method while at the same time measuring acoustic emissions from drying wood. When the electric complex spectrum and acoustic emission response are determined, it is possible to estimate both the main reason for the stresses (moisture gradient) and the outcome (micro- and macro-cracking). Thus the results may be used to control drying in order to achieve wood products of high quality.

Combination of the EIS and AE techniques allowed us to develop more comprehensive solutions to monitor and control wood quality during drying (Tiitta et al. 2007). These techniques were used first in laboratory tests and then in industrial wood drying kiln (Fig.2). The first prototype included two measurement channels for both AE and impedance. Temperature and four channels for MC measurement using electrical resistance pin electrodes were also included for reference MG measurements. Cooled instrumentation box was installed inside an industrial kiln for the tests. AE sensors and impedance electrodes were attached between the lumber boards on the upper surface. Labview based program was used for the measurements. Significant correlations between moisture gradient and impedance responses were found when using resistance pin electrodes for reference technique to evaluate moisture gradient during the drying process. For individual dryings, the correlation between impedance response and moisture gradient was typically about 0.9. The overall correlation between impedance response and moisture gradient was 0.8 when all successful measurements were analyzed with the same method. The inaccuracy of the reference method affected the results. The relation between AE responses and cracking was evident: correlation between surface cracking and AE count number was 0.81 when all successful measurements were included.

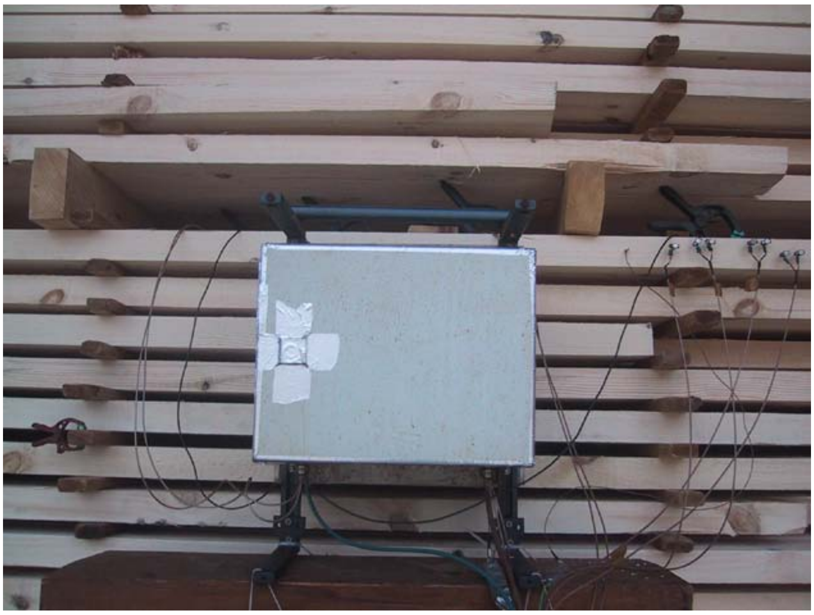

Figure 2. The combined AE and EIS measurement system was installed in an industrial drying kiln. The heat insulated and cooled box contains AE preamplifiers and the impedance modules. The pin electrodes were used for reference MG measurement using commercial resistance moisture meter.

4 Ultrasonic studies

Ultrasonic studies were conducted for veneer sheets (Tomppo et al. 2008). In the study, the lathe checks in birch veneer were examined with contact ultrasound and air-coupled ultrasound. Air-coupled method was used for green birch veneer and the contact measurements were conducted from dry veneer and then from moistened veneer. Several ultrasound parameters measured from dry veneers were related with lathe check depth, e.g. correlation between ultrasound transit time and lathe check depth was 0.63 ($p < 0.001$, $N = 30$) when measuring perpendicular to grain from unchecked face of the veneer. The same correlation for moistened veneers was 0.74 ($p < 0.01$, $N = 12$). In air-coupled through-transmission measurements, it seemed that moisture content dominated the measurement when measuring parallel to checks.

5 Using EIS and ultrasound for analyses of heat-treated wood

During the heat treatment of wood certain chemical, physical and structural changes occur in wood. In this application, properties of heat-treated wood were studied using electrical and ultrasonic methods. Moisture content, density, growth ring angle, hardness, strength and moisture properties were analyzed and compared with the electrical and ultrasonic properties of tested pine samples (Miettinen et. al 2005). The ultrasonic and electrical parameters had significant correlations, e.g. with moisture content and hardness. Using multivariate analysis density could be estimated with an accuracy of 20 kg/m^3.

6 Using EIS and IR for mould analyses

The aim of this study was to investigate whether EIS and FTIR are feasible non-destructive techniques to detect early stages of mould and monitor the growth of mould (Tiitta et al. 2009). Scots pine heartwood specimens were exposed to mould in controlled humid atmosphere (RH 95%, T=20 °C) and the responses of electrical impedance and Fourier transform infrared spectroscopy (EIS and FTIR) methods were studied. FTIR spectra showed that the relation of amide (1655 cm^{-1}) and carbonyl peaks (1736 cm^{-1}) was significantly affected by mould. In the EIS analyses, there were also electrical parameters, which were significantly affected by mould. In conclusion, both spectral methods hold potential for non-destructive mould detection and monitoring of mould development.

7 Gamma-ray studies

Gamma ray attenuation methods for measuring density and MC distributions of wood products were studied (Tiitta et al. 1993, Tiitta et al. 1996). Local density distributions of wood specimens (thickness 20-70 mm) were measured using an ^{241}Am (59.5 keV) gamma ray attenuation technique. A very low energy gamma ray attenuation technique (^{55}Fe, 5.9 keV) was used for the measurement of density distributions of veneer sheets (thickness 1-3 mm). Automated equipment was constructed and modified for each application (Fig.3). Excellent correlations were observed between the densities measured by the gamma attenuation method and gravimetrically measured densities: correlation coefficient *r* was over 0.9 in each calibration test.

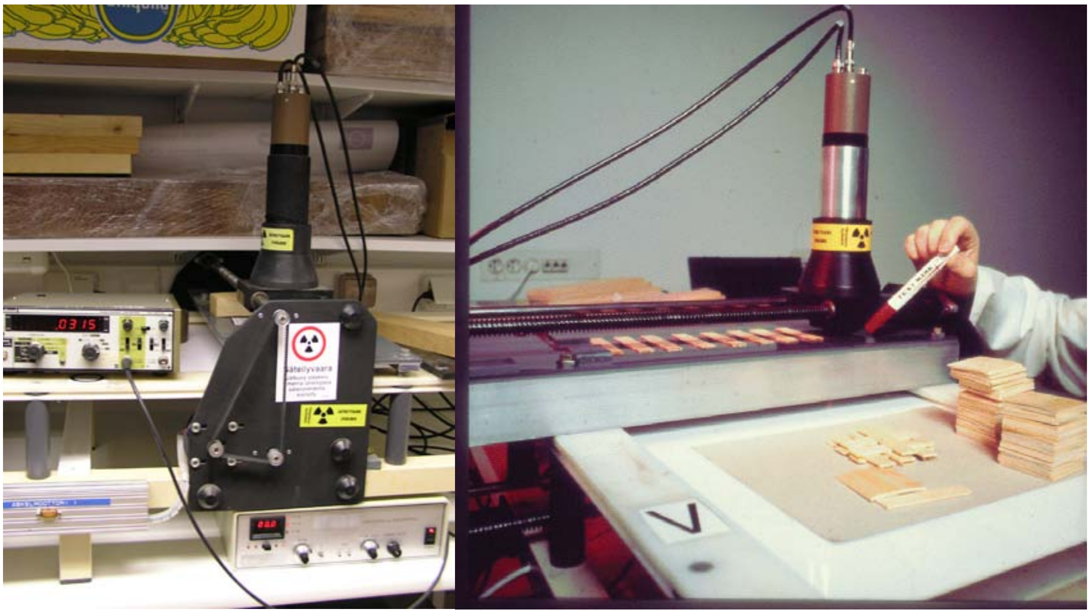

Figure 3. Gamma ray measurement of wood and veneer sheet specimens.

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