Acoustic and electromagnetic methods for wood

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Abstract

The basis of our work was to examine the relations between the wood properties and the responses of non-destructive methods with emphasis on spectroscopic analyses of distributions and gradients. The main goals were to develop improved methods and equipment for monitoring and characterisation of the internal properties of wood.

Acoustic emission technique has been studied especially for monitoring wood drying. Electromagnetic spectral techniques have been studied including frequencies from mHz to GHz region. Electrical impedance spectroscopy (EIS) based methods have been studied using electrical model analyses for evaluation of moisture content and moisture gradient. Novel electrical models and techniques were studied and portable EIS equipment was developed for moisture gradient analysis.

Combination of acoustic and EIS method has been studied for monitoring drying of wood including different types of heat modifications. A new method and a prototype have been developed. The method is based on using electrical method for moisture gradient monitoring and acoustic emission method for detection of micro-cracking during wood drying. 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 responses are determined at the same time, it is possible to estimate both the main reason for the drying stresses (moisture gradient) and the outcome (micro- and macro-cracking). Thus the results may be used to advantage in controlling drying in order to achieve wood products of high quality.

Introduction

Density and moisture content affect the physical and mechanical properties of wood with the effect of moisture content being especially important below the fibre saturation point [1]. Moisture gradient (MG) is also involved in wood in both the dried and green states. Moisture content and the chemical properties are significant factors in mould and decay development in wood. Therefore, knowledge of the properties and condition of wood is of the utmost importance at each stage of wood processing from growing trees to the final wood product.

Nowadays, sampling and destructive testing methods are still frequently needed to investigate the wood properties [2-4]. The optimum solution would be to use fully non-destructive evaluation. The basis of our work was to examine the relations between the wood properties and the responses of non-destructive methods with emphasis on spectroscopic analyses of distributions inside wood. The examined wood properties include moisture, moisture gradient, density and extractive content. Studies have been made from green to dried state including birch, pine and spruce species. Many types of timber boards and round wood have been studied.

In this paper, emphasis is put on two NDE methods and the combination of them: electrical impedance spectroscopy (EIS) and acoustic emission (AE). EIS is based on relatively low frequency electromagnetic waves and uses spectral and model analyses to enhance the evaluation [5]. 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). Many different
processes take place throughout the material when it is electrically stimulated and these lead to
the overall electrical response. In a test, electrodes are used to introduce a changing electric field
into the material and the spectral responses are measured. Electrical model analyses are used to
study the electrode-material interface and the material. Numerous successful applications include
corrosion testing, coating testing, electrical impedance tomography, body composition testing and
there are also many other biomaterial applications.

AE analysis is useful method for the investigation of local damage and fracture mechanics in
wood [6-7]. Process monitoring studies has been conducted using AE e.g. wood drying,
machining and adhesive curing has been monitored [7-10]. AE has been used to minimize defects
during wood drying [11-14]. Wave pattern recognition analyses have been widely used in AE,
typically several AE parameters are determined from the measured signals. The parameters
include, e.g. AE event rate, amplitude, energy, signal length, and several frequency domain
parameters.

Experimental

Commercial HP4284A, Hioki 3531Z and Solartron 1260/1296 impedance analyzers were used
in the laboratory studies of EIS covering frequency range 20 Hz – 10 MHz. Many types of
electrode configurations were examined to find out the best solutions for each type of
measurement. Birch, spruce and pine were the studied species. Detailed specifications for each
study can be found [15-18].

Our first developed EIS device [16] consists of a measurement probe and a control unit. The
hand-held probe consists of a measuring card and plate electrodes. The probe is laid against the
surface of wood during measurement. The probe can also be placed in a holder for continuous
measurement. In the continuous measurement, a graph of transverse moisture gradient and
estimates of minimum, maximum, surface, and average MC are displayed on the screen. Also
multichannel EIS measurement systems have been developed and used in many applications
(Fig.1).

Fig.1. Laboratory testing of our eight channel impedance measurement system.
Both acoustic emission and impedance measurements were first conducted in laboratory. Laboratory oven was modified to control the relative humidity and temperature inside the oven. Many different types of drying schedules and wood samples were tested. In the drying, continuous AE measurement was attached to the drying wood samples using 150 kHz AE sensors (Vallen-150M) connected to a preamplifier (Vallen-AEP3). In simultaneous impedance measurements, different types of parallel plate electrodes and pin electrodes were tested. LabView based program was developed to collect impedance and AE measurement data.

After a few years of laboratory testing, an industrial prototype was developed (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. Peltier element cooled instrumentation box was installed inside an industrial kiln for the tests. The box contained impedance modules and AE preamplifiers. AE sensors and impedance electrodes were attached between the lumber boards on the upper surface.

![Image of measurement system](image.png)

**Fig.2.** The combined 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.

**Results**

The industrial tests were carried out for several months. The correlation between impedance response and moisture gradient measured by electric DC-resistivity measurement by pins was 0.8 for thick samples (thickness 63-70 mm) when all successful measurements were analyzed. The problem with the tests was that there was no reliable reference moisture gradient measurement method when the moisture content was above fiber saturation point. The correlation between the amount of surface cracking after drying and cumulative AE count number was 0.8 when all successful measurements were included.

Examples of the measurement responses from industrial dryings are represented (Fig.3 and Fig.4). Moisture gradient measured using pin electrodes and electrical impedance spectroscopy gave similar results (Fig.3) when moisture content level was below fiber saturation point (approximately 25-30% for pine). Acoustic emission responses were measured using several
voltage threshold levels and analyzed using signals which were within certain amplitude level. Quite low amplitude signals gave the best relation compared to surface cracking. Examples of AE responses of timber boards with high and low level of surface cracking after drying are represented when using voltage range 0.5 V – 1 V (Fig.4).

Fig.3. Example of measurements in industrial drying kiln during drying and conditioning, a) moisture gradient determined from impedance response and b) moisture gradient determined from the difference of DC pin resistance measurements (pins were inserted at 1/6 and 1/2 thickness (Fig.2), board dimension 65 x 208 mm).
Discussion

The study presents results of the first long-term industrial testing of the combined acoustic and electric method. Though there were a huge number of technical challenges and problems, most of the long-term runs were completely successful for monitoring the drying. Indeed, there were more problems with the DC-resistance pin electrode measurement than in the impedance method, which could be used for monitoring in all tests. Monitoring of AE was very challenging because some noise is always present in the industrial process. Despite all the problems, it was also possible to carry out quantitative comparison of the responses to reference methods which were pin resistance method for EIS responses and visual analysis for AE responses. Especially AE technique needs to be further studied and developed to achieve more accurate results.

Conclusions

Laboratory and industrial studies and tests were conducted using electrical impedance and acoustic emission methods. The combination of methods may be used for monitoring and also controlling wood drying to improve quality of dried wood.

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