Combined method for monitoring wood drying process

Markku Tiitta, Laura Tomppo, Reijo Lappalainen

Univ. of Eastern Finland, Dept. of Physics and Mathematics, Kuopio, Finland

OVERVIEW

Combined method:
- multi-parameter analyses

Electrical impedance spectroscopy (EIS):
- moisture gradient analysis

Acoustic emission (AE):
- micro-cracking

Wood drying:
- laboratory analyses using individual methods
- laboratory analyses using combined method
- industrial tests

Prototypes:
- developed for EIS, AE and combined methods
Acoustic emission

AEs are commonly defined as transient elastic waves within a material caused by the release of localized stress energy.

Number of AE events is high at high stress levels.

It is possible to observe early structural changes in materials.

AE has been widely used in inspection, quality control, system feedback, process monitoring etc.

AE is related to an irreversible release of energy.

Typically in ultrasonic frequencies.

Analysis of AE event rate, signal amplitude and frequency.

AE signal in time and frequency domain
Drying of a small pine timber board: simulated stress 3 mm below surface and measured AE response: AE count vs. drying time

**Electrical impedance spectroscopy**

Electrical impedance spectroscopy (EIS, IS) has been widely used to study different types of biological materials.

One of the main applications has been to study fundamental electrical properties of materials and correlate these properties with material structure.

It 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 lead to the overall electrical response.

The system may be analyzed by using equivalent circuit modelling.
Impedance models for one sided (a, b), through-transmission measurement (c, d) and the CPE (e).

Examples of impedance spectra and fits for wood moisture gradient measurement. One sided measurement using stainless steel plate electrodes. Both wood samples have the same average moisture content (15%) near the surface.
EIS-device for moisture gradient measurement

Species, number, size and RH condition of specimens for the EIS analyses.

<table>
<thead>
<tr>
<th>Species</th>
<th>N</th>
<th>Analysis</th>
<th>Size (T x W x L, mm)</th>
<th>RH%</th>
<th>MC %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pine</td>
<td>18</td>
<td>MG</td>
<td>(1/2/4/10/25) x 90 x 150</td>
<td>35-90</td>
<td>8-22</td>
</tr>
<tr>
<td>Birch</td>
<td>40</td>
<td>MC</td>
<td>(28-33) x 100 x 150</td>
<td>35-80</td>
<td>8-15</td>
</tr>
<tr>
<td>Spruce</td>
<td>66</td>
<td>MC</td>
<td>(23-51) x 100 x 150</td>
<td>35-80</td>
<td>8-19</td>
</tr>
<tr>
<td>Pine</td>
<td>52</td>
<td>MC</td>
<td>(26-52) x 150 x 100</td>
<td>35-80</td>
<td>7-18</td>
</tr>
<tr>
<td>Spruce</td>
<td>60</td>
<td>MG calibration</td>
<td>(19-26) x 100 x 150</td>
<td>35 – 100</td>
<td>8-40</td>
</tr>
<tr>
<td>Spruce</td>
<td>47</td>
<td>MG test</td>
<td>(20-25) x 100 x 150</td>
<td>35 - 100</td>
<td>8-30</td>
</tr>
</tbody>
</table>
Comparison of a commercial capacitance moisture meter and EIS meter. Average differences (Δ) in moisture content readings compared to the weighing/drying method.

<table>
<thead>
<tr>
<th>Moisture gradient</th>
<th>N</th>
<th>MC range (%)</th>
<th>Capacitance meter Δ (%)</th>
<th>Impedance meter Δ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desorption</td>
<td>12</td>
<td>10-30</td>
<td>7.6</td>
<td>0.8</td>
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<tr>
<td>Absorption</td>
<td>10</td>
<td>10-24</td>
<td>6.5</td>
<td>1.8</td>
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<tr>
<td>Insignificant</td>
<td>25</td>
<td>8-14</td>
<td>1.6</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Pulpwood measurement configuration
Industrial tests

The tests were carried out for several months.

Different drying schedules were used when continuously measuring AE and impedance responses from timber boards in the kiln.

The thickness of pine boards varied from 52 to 70 mm.

The overall correlation between impedance response and moisture gradient determined using the pin resistance meter was 0.8 when all successful measurements were analyzed.

The correlation between surface cracking and AE count number was 0.81 when all successful measurements were included.

Measurement system was installed in a drying kiln. The heat insulated and cooled box contains AE preamplifiers and the impedance modules.
Measurement from an industrial timber drying kiln, drying from a pine board (65 x 208 mm): impedance response as a function of moisture gradient measured by pin electrodes at different depths using resistance method.

Measurement from industrial timber dryings (7 loads). Measurements from pine boards (thickness: 63-70 mm): impedance response as a function of moisture gradient measured by pin electrodes at different depths using resistance method.
AE count number of two pine boards (thickness 65 and 67 mm) as a function of drying time: red – surface cracking 58.3 %; blue - surface cracking 17.7 %.

Amplitude spectrum of the cumulative AE count of two pine boards (thickness 65 and 67 mm): red – surface cracking 58.3 %; blue - surface cracking 17.7 %.
Logarithm of cumulative AE count number as a function of visually detected surface cracking after industrial kiln drying (11 loads).

Novel AD5933 impedance converter chip was used for 8 channel impedance measurement: electronics and mechanics were developed.
Summary

fully nondestructive analysis:
a coustic emission
electrical impedance spectroscopy
multi-parameter analysis

analysis of moisture gradient and surface cracking
monitoring stress development in wood during drying
computer equipped relatively low cost method