WATER DETECTION AND QUANTIFICATION IN POLYMERS USING A NON-DESTRUCTIVE MICROWAVE TECHNIQUE

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Introduction
Water content as a basic aspect of component’s quality
Introduction
Water content in polymers

Material processing (extrusion)
Bonding technology

Bonding after:
Surface quality tests
Storage
Repairing process
Introduction
Research strategy
Introduction
Device properties

PORTABILITY

EASE TO USE

PRODUCTION PROCESS

FAST MEASUREMENT

HIGH ACCURACY

HIGH INFORMATION DEPTH
Introduction
Physical principle

Microwave resonator

Open end

Electric fieldlines

Transmission
Resonance frequency

Parameters for moisture content quantification

Decrease of resonance frequency, $A$
Increase of bandwidth, $B$

Dried epoxy
Saturated epoxy

Dried Epoxy
Saturated Epoxy
Experimental part
Sample preparation

**DRYING PROCESS**

70 °C
0% rh

Silica gel

Reference weight
(m_d)

**SATURATION PROCESS**

70 °C
Different rh

Oversaturated salt solution

Weight at saturation
(m_sat)

\[ MC = \frac{m_{sat} - m_d}{m_d} \times 100 \]
Moisture Content
Polyamide-6

- Polyamide-6 calibration using \( \arctan(B/A) \) as quantifying parameter

\[
\phi = \arctan(B/A)
\]

Increase of bandwidth, B [MHz]

\[
\begin{align*}
0.35 \text{ mm} & \\
0.70 \text{ mm} & \\
1.05 \text{ mm} & 
\end{align*}
\]

Change of resonance frequency, A [MHz]

0 \quad 5 \quad 10 \quad 15 \quad 20

0 \quad 0.5 \quad 1.0 \quad 1.5 \quad 2.0 \quad 2.5 \quad 3.0 \quad 3.5
Moisture Content Polyamide-6

- Polyamide-6 calibration using $\arctan(B/A)$ as quantifying parameter

\[ MC = \frac{-0.0029 + \sqrt{0.0029^2 - 0.0096 \cdot (0.0031 - \arctan(B/A))}}{0.0048} \]
Moisture Content
Epoxy

- Epoxy calibration using $\arctan(B/A)$ as quantifying parameter

![Graph showing the relationship between the increase of bandwidth and the change of resonance frequency for different moisture contents.](image)
Moisture Content
Epoxy

Epoxy calibration using $\arctan(B/A)$ as quantifying parameter

$$MC = \frac{\arctan(B/A) - 0.0504}{0.0183}$$

[Diagram showing a graph with the equation and data points]
Moisture Content
Epoxy

- Epoxy calibration using \( \arctan(B/A) \) as quantifying parameter at different temperatures:

\[
\text{arctan}(B/A) \text{ increase } = +0.007/ 10^\circ C
\]
"In progress" investigations
Partially conducting composite materials

- Carbon fiber reinforced polymer
Conclusions

- Polyamide-6 and Epoxy

<table>
<thead>
<tr>
<th></th>
<th>Detection</th>
<th>Quantification</th>
<th>Fitting</th>
<th>Detection limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyamide-6</td>
<td>✔</td>
<td>✔</td>
<td>Polynomial</td>
<td>0.56 - 2.04 %wt</td>
</tr>
<tr>
<td>Epoxy</td>
<td>✔</td>
<td>✔</td>
<td>Linear</td>
<td>0.13 - 0.54 %wt</td>
</tr>
</tbody>
</table>

- In progress research on partially conducting materials (CFRP)
- Continuous development together with the device manufacturer
  - Sensor geometry
  - New frequencies for specific water states and materials
THANK YOU!

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