Classification of material sensitivity –
New approach for mould growth modeling

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Outline

- Background – Existing mould growth model for wood
- Model parameters and their adjustment for different materials
- Formulation of material sensitivity classes
- Evaluation of the improved model
- Discussion and conclusions

Acknowledgement
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Existing model for pine sapwood

- The model is based on visual findings of mould
- The rate of mould growth is presented as MOULD INDEX $[0, 6]$
- Mould index can be solved numerically
  - parallel with HAM simulations or as a post processing tool

Critical factors:
- Moisture
- Temperature
- Time
- Substrate
Mould Index – Values for visual observations of the growth level

<table>
<thead>
<tr>
<th>Index</th>
<th>Description of the growth rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No growth</td>
</tr>
<tr>
<td>1</td>
<td>Small amounts of mould on surface (microscope), initial stages of local growth</td>
</tr>
<tr>
<td>2</td>
<td>Several local mould growth colonies on surface (microscope)</td>
</tr>
<tr>
<td>3</td>
<td>Visual findings of mould on surface, $&lt; 10%$ coverage, or, $&lt; 50%$ coverage of mould (microscope)</td>
</tr>
<tr>
<td>4</td>
<td>Visual findings of mould on surface, $10 - 50%$ coverage, or, $&gt;50%$ coverage of mould (microscope)</td>
</tr>
<tr>
<td>5</td>
<td>Plenty of growth on surface, $&gt; 50%$ coverage (visual)</td>
</tr>
<tr>
<td>6</td>
<td>Heavy and tight growth, coverage about $100%$</td>
</tr>
</tbody>
</table>
Objectives for model development

- Improved tool for prediction of mould growth on typical building materials
- The same mould growth parameters are used for all materials
- Scaling factors for material sensitivity classes
Mould growth parameters used in the numerical model

- Substrate, typical building materials
- Growth conditions (RH and temperature)
- Growth intensity
- Maximum growth (Mould index) level
- Decline of visible growth level during unfavorable conditions
- Restarting of growth
Mould growth conditions

- Pine sapwood

![Diagram showing mould growth conditions based on temperature and relative humidity (RH)].

- Too dry
- Too cold: growth stops
- Too hot: mould risk is high
- Mould risk possible: $t_m = 4\text{ weeks}$
- Mould risk possible: $t_m = 8\text{ weeks}$
Mould growth intensity

Growth intensity at different stages
Mould growth level

Temperature, relative humidity and material

Maximum level of mould index under prevailing conditions
Mould index decline

Unfavourable conditions for growth – cold or dry season
Restart of mould growth

Delays and intensity of restarting growth
Experimental research for determination of material parameters and evaluation of the model

Samples under constant /cyclic conditions | Material samples in outdoor conditions
---|---

Material interfaces - structures in lab. | Structures in outdoor conditions
Mould index [0, 6] detected in different materials

- **M = 1**
  Aerated cellular concrete

- **M = 3**
  PUR + paper surface

- **M = 3 - 4**
  Concrete

- **M = 5 - 6**
  Wooden board
Experimental findings - Mould growth intensities on materials

RH 97 %, 23 °C

- particle board
- fibre board
- plywood
- gypsum
- concrete
- concrete
- cement screed
- pine

Mould index

Time (week)
Mould growth intensity classes

RH 97 %, 23 °C

- particle board
- fibre board
- plywood
- gypsum
- concrete
- cement screed
- pine

Time (week)

Mould index
Maximum mould index levels under constant conditions

RH 97 %, 23 °C

Maximum levels of growth

Classification

<table>
<thead>
<tr>
<th>Material</th>
<th>Mould index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle board</td>
<td>5.5</td>
</tr>
<tr>
<td>Fibre board</td>
<td>5.0</td>
</tr>
<tr>
<td>Plywood</td>
<td>4.5</td>
</tr>
<tr>
<td>Gypsum</td>
<td>4.0</td>
</tr>
<tr>
<td>Concrete</td>
<td>3.5</td>
</tr>
<tr>
<td>Cement screed</td>
<td>3.0</td>
</tr>
<tr>
<td>Pine</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Nordic Symposium on Building Physics, 29th May - 2nd June 2011, Tampere
General mould growth equations –
Reference material pine

\[
\frac{dM}{dt} = \frac{1}{7 \cdot \exp(-0.68 \ln T - 13.9 \ln RH + 0.14W - 0.33SQ + 66.02)} k_1 k_2
\]

\[
k_1 = \begin{cases} 
  t_M = 1, \text{pine}, & \text{when } M < 1 \\
  t_{M=1} & \\
  2 \cdot \frac{(t_{M=3, \text{pine}} - t_M = 1, \text{pine})}{(t_{M=3} - t_{M=1})}, & \text{when } M \geq 1
\end{cases}
\]

\[
k_2 = \max[1 - \exp[2.3 \cdot (M - M_{\text{max}})], 0]
\]

\[
M_{\text{max}} = A + B \cdot \frac{RH_{\text{crit}} - RH}{RH_{\text{crit}} - 100} - C \cdot \left(\frac{RH_{\text{crit}} - RH}{RH_{\text{crit}} - 100}\right)^2
\]

‘Scaling factors’

Coefficient \( k_1 \) is used to scale the growth intensity

Coefficient \( k_2 \) to limit the growth to maximum index level
Four mould growth intensity classes

Experiments

Material classes

<table>
<thead>
<tr>
<th>Sensitivity class</th>
<th>$k_1$ (M &lt; 1)</th>
<th>$k_1$ (M ≥ 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>very sensitive</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>sensitive</td>
<td>0.578</td>
<td>0.386</td>
</tr>
<tr>
<td>medium resistant</td>
<td>0.072</td>
<td>0.097</td>
</tr>
<tr>
<td>resistant</td>
<td>0.033</td>
<td>0.014</td>
</tr>
</tbody>
</table>

Very sensitive = pine sapwood
Experimental findings are interpreted with ‘scaling’ coefficients $k_1$
k_1 values are determined for material sensitivity classes
Maximum growth level – Classification using coefficient $k_2$

\[ M_{\text{max}} = A + B \cdot \frac{RH_{\text{crit}} - RH}{RH_{\text{crit}} - 100} - C \cdot \left( \frac{RH_{\text{crit}} - RH}{RH_{\text{crit}} - 100} \right)^2 \]

<table>
<thead>
<tr>
<th>Sensitivity class</th>
<th>$k_2$</th>
<th>RH$_{\text{min}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>very sensitive, vs</td>
<td>1 7 2</td>
<td>80</td>
</tr>
<tr>
<td>sensitive, s</td>
<td>0.3 6 1</td>
<td>80</td>
</tr>
<tr>
<td>medium resistant, mr</td>
<td>0 5 1.5</td>
<td>85</td>
</tr>
<tr>
<td>resistant, r</td>
<td>0 3 1</td>
<td>85</td>
</tr>
</tbody>
</table>

Values for new sensitivity classes

Pine, reference

‘Scaling’ coefficients $k_2$ are derived from experimental findings
Sensitivity classes and experimental findings under constant conditions

Pine and spruce under 97 % RH and +5 °C

<table>
<thead>
<tr>
<th>Sensitivity Class</th>
<th>Lines Color</th>
<th>Graph Symbols</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very sensitive</td>
<td>Red</td>
<td>-</td>
</tr>
<tr>
<td>Sensitive</td>
<td>Orange</td>
<td>-</td>
</tr>
<tr>
<td>Medium resistant</td>
<td>Green</td>
<td>-</td>
</tr>
<tr>
<td>Resistant</td>
<td>Blue</td>
<td>-</td>
</tr>
</tbody>
</table>

- Surface 1, S+
- Surface 2, S-
- Pine sapwood
Experiments vs. sensitivity classes

Concrete under 97 % RH and +22 °C

- very sensitive
- sensitive
- medium resistant
- resistant
- Surface 1, S+
- Surface 2, S+
Decline of Mould Index – Seasonal effects on growth level

\[
\frac{dM}{dt}_{mat} = C_{mat} \cdot \frac{dM}{dt}_{Pine}
\]

Correlations factors for mould index decline

<table>
<thead>
<tr>
<th>(C_{mat})</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Pine in original model, short periods, significant decline</td>
</tr>
<tr>
<td>0.5</td>
<td>Relevant decline</td>
</tr>
<tr>
<td>0.25</td>
<td>Relatively low decline</td>
</tr>
<tr>
<td>0.1</td>
<td>Almost no decline</td>
</tr>
</tbody>
</table>
Model evaluation – Simulation of experiments

- Interface of two materials inside a structure
- The conditions (RH and T) and the mould index levels were monitored
- RH and T values used in simulations
- Model parameters were adjusted according to material sensitivity classes

![Graph showing interface of two materials, mould growth, mould decline, and growth after decline over dates from 2.7.06 to 25.10.07 with temperature (T, °C) and relative humidity (%RH) on the y-axis and date on the x-axis.](image)
Measured vs. simulated: Concrete and paper covered polyurethane foam insulation (PUR)
Case 3: Spruce board and glass wool insulation
## Mould growth sensitivity classes for materials used in this research

<table>
<thead>
<tr>
<th>Mould sensitivity class</th>
<th>Typical materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very sensitive</td>
<td>Untreated wood, Materials including nutrients</td>
</tr>
<tr>
<td>Sensitive</td>
<td>Planed wood, Paper coated products, Wood based boards</td>
</tr>
<tr>
<td>Medium resistant</td>
<td>Cement based materials, Plastic based materials, Mineral fibers</td>
</tr>
<tr>
<td>Resistant</td>
<td>Glass products, Metal products, Materials with protective compound treatments</td>
</tr>
</tbody>
</table>
Summary

- Improved mould growth model for general building materials
- Mould growth sensitivity classes are used to present different materials
- Sensitivity class factors:
  - Limit conditions for growth
  - Mould growth intensities
  - Maximum mould growth levels
  - Decline of mould under cold or dry periods
- Classification makes it possible to do sensitivity analysis also for biological growth
- The sensitivity classes of materials / products have to be considered and set separately
- Mould growth is one of the performance criteria of structures
Thank you!