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RESEARCH ARTICLE

MATHEMATICAL BASED MODEL OF *STREPTOMYCES* GROWTH ON WOODEN MATERIAL

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ABSTRACT

A mathematical model for the growth of filamentous microorganisms has been tested by comparison of model predictions with data on growth of *Streptomyces* on building wood material. Growth of Streptomyces resulted in movement of filament classes to increasing the size, while shear forces produced mycelial fragments which entered the smallest size class, from which they grew to form further colonies on building surface materials. Quantification of *Streptomyces* growth in the model is based on the mould index used in the experiments for visual inspection. The model consists of differential equations describing the growth rate of the mould index in different fuctuating conditions including the effect of exposure time, temperature, relative humidity and dry periods. Temperature and humidity conditions favourable for mould growth are presented as a mathematical model. The modified model generated predictions which agreed closely with experimental data on biomass concentration, distribution, number of colonies and colonies radius during their growth on building wood material, thereby supporting the assumptions on which the model was based. The numerical values of the parameters included in the model are fitted for pine and spruce sapwood, but the functional form of the model can be reasoned to be valid also for other wood-based materials.

Keywords: streptomycetes, mathematical model, building materials, humidity, temperature

INTRODUCTION

The growth form of filamentous micro-organisms in building wood material ranges from discrete compact colonies to homogeneous dispersed mycelia. The relative quantities of each type, together with colonies surface interactions, influence the viscosity, mass transfer and rheological characteristics of wood materials (Adan, 1994)[1]. The viscosity of growth of *Streptomyces* colonies (Williams and *et al*., 1989)[2] is low and consequently mixing and mass transfer are maintained during their growth. This contrasts with dispersed mycelial growth for which such gradients do not exist. This growth form does, however, present disadvantages in that mycelia may wrap around impellers and probes and may cause blockages, leading to contamination of sampling and overflow lines. Streptomycetes play important functional role in natural and man-made environments. In nature, these play a crucial role in the decomposition of organic compounds and environmental pollutants (Cross, 1982)[3]. In buildings, actinomycetes cause problems in different structure and materials like basements, floors, roofs and walls. Surfaces of many other materials support the growth of microbs viz., bacteria, actinomycetes and fungi which are more common for material decay damages. The ambient relative humidity (RH, relative humidity of microclimate) above 75%–80% or water activity (a_w) above 0.75-0.80 is critical for the development of actinomycetes on the surface of wood, but the critical humidity level is also dependent on temperature and exposure time (Viitanen and Ritschkoff,1991)[4]. It has been found that the actinomycetes growth on other building materials may not be equal to that on wood based materials (Ritschklff and *etal*., 2000)[5]. These microorganisms produce aesthetic or technical effects and the requirements for repairing the problems and damages are different. Also the exposure time needed for the microbial growth to begin may be longer. Moisture damage buildings may lead to the growth of microorganisms which damage to building materials after a critical exposure time.

EXPERIMENTAL MATERIAL

The experimental material consisted of small samples (5 ´ 10 ´ 50 mm) of pure dried pine and spruce sapwood. Two different surface qualities differing in nutrient content were studied: original dried and resawn. Certain preconditions must be assumed concerning these experiments:

(i) The small samples used to describe the *streptomyces* growth on wooden material reaching the equilibrium moisture content without delay. The definite size of the samples may thus be neglected as well as the delay in the wood cell wall attaining the equilibrium moisture content prescribed by the surrounding relative humidity.

(ii) The growth of mould fungi takes place only on the material surface and it may thus be modeled using only surface temperature and moisture content as input data.

(iii)The existence of *streptomyces* on the material surface does not influence the moisture behavior of the wood material, e.g. sorption properties.

The Actinomycetes was measured applying an existing standard index based on the visual appearance of the surface under study. Some refinement has been made concerning the scale and as a result this mould index assumes following integer values:

Table 1 Actinomycetes Growth Index

Index Values	Growth Rate	Description
0	No growth	Spores not activated
1	Mould growth in small amount occurs on surface	Initiation phase
2	<10% Coverage of mould on surface	-
3	10-30% or <50% Coverage growth on surface	New spores produced
4	>50% Coverage of mould growth	Moderate growth
5	>70% Coverage growth on surface	Plenty growth
6	Very high and dense growth about 100% coverage surface	

Actinomycetes index and t is the time (h) for the moment t_1 when conditions on the critical surface changed from growth to outside growth conditions (Hukka and Viitanen, 1999). Under the long periods (week, months), gives practically linear decrease of mold index. The decline stage of mold index for other material was presented using a relative coefficient for each material as Equation (1). So that the decline model for wood could be applied using these additional factors (Hukka and Viitanen, 1999)[6].

$$\left(\frac{dA}{dt}\right) mat = Cmat(dA/dt)0 \qquad (1)$$

Where $(dA/dt)_{mat}$ =actinomycetes decline intensity for each material, $(dA/dt)_0$= pine in orogonal model, $C_{mat=}$ relative coefficient for mold index decline used in the simulation model.

RESULTS AND DISCUSSION

The results were expressed as accordingly to mold index level 1to 6 (Table 1). Experiments were done to take better accounts the different *Streptomyces* growth types with different surface and wood material. The main differences compared with the version for wood surfaces (Vinha and *et al*., 2006)[7] was in the area that is not visible to naked eye (microscopic). It was found out that with some substrates the mold growth coverage could be quite high in the microscopic level. Therefore, the mold growth index determination was updated with initiation of mold growth equivalent to index level 1. Model index level 3 and higher equates with visible mold growth coverage (macroscopic).

The various building materials showed varying tolerance against mold growth under the test conditions. The results of wood substrate and other material surfaces fitted best with pine sapwood. At the 15˚C temperature, there was a lag phase for the initiation of mold growth, so this was no well fitted with this model. The second evaluation of the mold growth model with the new material sensitivity class factors (Table 2) was done by producing mold index levels under constant temperature and relative humidity. The maximum level of mold index for different materials under different temperature and relative humidity are presented in Table 3. All data of Tables (2 and 3) determined the best approximation based on different numerical post processing of the experimental results.

Table 2: Different sensitivity class of the *Streptomyces* on wood surface material model based on VTT model

Sensitivity Class	Material	k_1		K_2 (max)			RH min(%)
		A<1	A>1	A	B	C	
Very sensitive	Pine sapwood	1	2	1	5	1	90
Sensitive	Wooden board, spruce	0.586	0.475	0.5	4	1	90
Medium resistant	Concrete, glasswool polyester	0.082	0.084	0	4.5	2	95
Resistant	PUR unpolished surface	0.021	0.011	0	2	0.5	95

Table 3: Maximum actinomycetes growth index for different material under using steady state conditions

Material	27˚C, 95% RH	15˚C, 95% RH	27˚C, 90% RH	15˚C, 90% RH
Pine sapwood	5.5	4	3.5	2.3
Spruce sapwood	5.1	4.5	2	1
Fiber board	4.3	3.5	1.3	0.9
Gypsum	2.1	1.1	0.6	0.5
Concrete	1.5	0.9	0.4	0.3

All building materials tested were susceptible to *streptomyces* growth in humidity higher than 90% RH at temperature above 27˚C. Actinomycetes were not found at lower humidity (below 90%) condition. Although, wood based materials needed lower critical humidity and exposure period for actinomycetes growth initiation (lag phase; A=1) and all tested material seemed to be most susceptible to biological attack or contamination. As data shown in Table 3, based on the exposure condition in the constant condition 95% RH, 27˚C and 90% RH, 15˚C. The actinomycetes growth was restarted due to low temperature and low relative humidity. This is because, this effect was also found in the modeled data for pine sapwood, but it was best fitted in tests using 97% relative humidity at 27˚C. This study is based on the experimentally detected actinomycetes index values on the critical interface of wall assemblies exposure under controlled relative humidity and temperature.

The actinomycetes index values were determined for substrate material surfaces on each critical interface. Figure1 showing the relative actinomycetes decline values (C_{mat}) solved from observations in the experiments. The results include the detected mean, minimum and maximum actinomycetes index values. The retarted intensity of actinomycetes on building material surfaces favourable growth conditions (Brischke and hansson, 2011)[8] could be presented as decline classes (Table 2). This classification is based on few measurements with relatively large scattering classes.

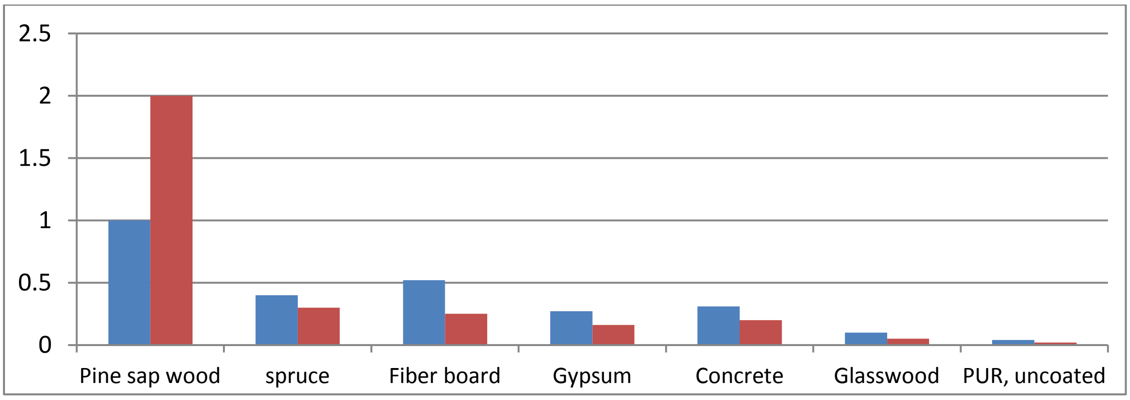

Figure 1: Actinomycetes growth factors (k_1) for different materials used in experiments

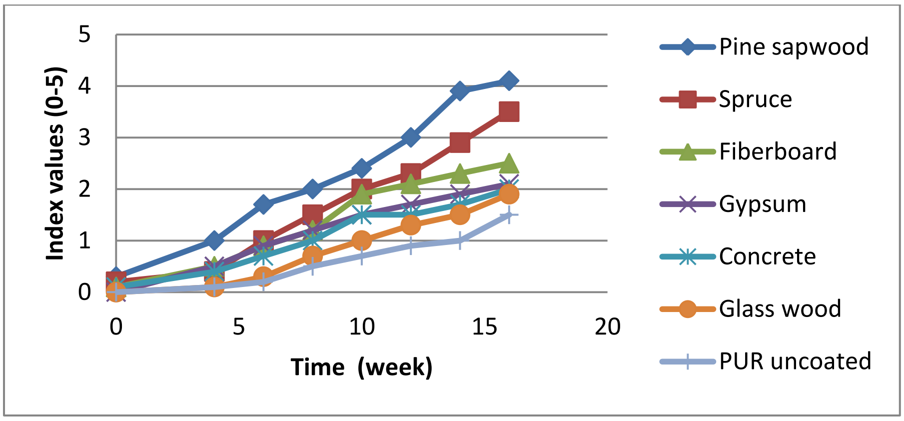

Figure 2: Numerically comparison between experimentally analyzed actinomycetes growth on different wood materials

Comparison of model results against experimental data

The presented mathematical model for actinomycetes growth is based on measured values from steady state and dynamic experiments of building materials. The largest possible value of actinomycetes index Eq. (1) is based on 12 week experiments in constant conditions. All building materials tested were susceptible to actinomycetes growth in humidities higher than 90% RH at temperature in between 15 to 25˚C.

The actinomycetes growth index mathematical model is based on steady state conditions and dynamic experiments of selected building materials: spruce wood, fiber board, gypsum, concrete, glasswool, PUR with paper. Pine sapwood was used as the reference material (Clark and et *al*., 1999)[9]. The most critical factors for actinomycetes and microbial growth

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development (Ritschkoff and *et al.*,2000)[5] are the relative humidity, pH, temperature conditions of material surfaces, exposure period (Table 2) and types and age of building materials. Althuogh, the required critical growth conditions of actinomycetes development can start updated the different material classes (Table 2). The decay of actinomycetes growth index level occur during cold or dry period which presents the relative coefficient value (Eq.1) for the decline intensity of different building material classes. The mathematical model does not make any distinction between actinomycetes growth, but it represents the risk for any possible actinomycetes growth on the material surfaces. The highest growth of actinomycetes in or on building material exists where the relative humidity is about 95 to 97%, temperature 27˚C and required nutrients.

CONCLUSION

In general, the higher the temperature and the more favourable the nutrition at a given relative humidity, the less time is required for spore germination. Temperature conditions have a minor effect on the water activity and the main effect is concerned with the growth and metabolic activity of the *Streptomyces*. This mathematical model is neither based on linear function nor does it provide one exclusive limit state, which might apparently conflict with the ideal preconditions on an engineering approach. Biodegradation of buildings and building materials depending on the, dimension of component, type of decay, Temperature and relative humidity. There are several factors involved with the microbial degradation of buildings and building materials by actinomycetes and other microbial consortia. The main motive of the actinomycetes growth index model development and application is nevertheless give a tools for better prediction and evaluation of the risk for microbial consortia growth on building material surfaces and capable to find the best solutions to ensure a safe performance for buildings and building materials.

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