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EFFECT OF LOAD BEARING MATERIALS ON SUSCEPTIBILITY TO BIOFILMS GROWTH

VÁCLAV KOČÍ and JIŘÍ MADĚRA

Dept of Materials Engineering and Chemistry, Faculty of Civil Engineering, Czech Technical University, Prague, Czech Republic

Preventing a biofilms growth on exterior facades of buildings is one of the ways how to preserve the original buildings appearance and thus their proper aesthetical function. Since the biofilms growth is strongly conditioned by the hygric and thermal conditions on the surface, a proper hygrothermal performance and interactions between materials involved is essential. This paper studies an impact of load bearing material on surface conditions on a lime-cement plaster from the point of view of susceptibility to biofilms growth. An influence of autoclaved aerated concrete, solid brick and sandstone is studied when exposed to dynamic boundary conditions in form of reference climatic data. Being obtained using computational modeling of coupled heat and moisture transport, the results revealed a substantial influence in that respect. The best performance exhibited the autoclaved aerated concrete as the duration of convenient conditions for biofilms growth was lower by 40% when compared to solid brick and sandstone.

Keywords: Computational modeling, Surface conditions, Hygrothermal patterns, Biodegradation, Lime-cement plasters.

1 INTRODUCTION

Preservation of original facades appearance is a very important task not only from the aesthetical point of view but also from the point of view of hygrothermal performance of facades materials and whole building envelopes, consequently. Despite aesthetical biodegradation that can affect only the color or facades' visual aspects, thin biofilm on a surface can emanate microorganisms' metabolites that can lead to chemical biodegradation and thus materials degradation. Furthermore, biodegradation has also physical aspects. It might change hygric or thermal properties of materials and thus their hygrothermal function, which can result into a physical damage of building materials.

The rate of damage is correlated with several factors. A type and size of microorganism, type of material (Tiano *et al.* 1995), environmental conditions (Garciapichel *et al.* 1993), exposure to microclimatic conditions or a type of air pollutant and its concentration (Tiano 2002) belong among the most significant in that respect. Hygric and thermal conditions on the surface are also very important, being dependent on a type of load bearing materials. Therefore, this research aims at evaluation of hygrothermal conditions of several building envelopes being composed of different types of materials. It exploited the possibilities of computational modelling to predict a hygrothermal behavior of building materials and elements when exposed to dynamic boundary (climatic) conditions.

2 BIOFILMS

The biodegradation of facades materials is mostly caused by biofilms covering material surfaces. The composition of biofilms is variable and depends on environmental or material actors (Gaylarde and Gaylarde 2005). Bacteria, fungi, algae, lichen and moss are the mostly contained organisms. Requiring just CO_2, N_2 and salt minerals traces (Tiano 2002), the algae and cyanobacteria represent usually pioneering inhabitants on a building materials surface. Due to their ability to etch mineral components they are able to initiate a degradation process (Danin *et al.* 1982), i.e. increase microcracks (Gaylarde *et al.* 2003) or form colored patinas (Dubosc *et al.* 2001).

According to the research presented by Kobetičová *et al.* (2019), the biofilms covering surfaces of lime or lime cement plasters may be formed by algae species *Hematococcus pluvialis* and *Klebsormidium sp.*, cyanobacteria of genus *Nostoc* and *Anabaena*, mold species *Aspergillus niger* or moss species *Ceratodon purpureus*. Taking into account the biofilm composition, the optimal hygrothermal patterns for biofilm growth can be set according to Dubosc *et al.* (2001) as depicted in Figure 1. They express a zone defined by combinations of temperature and relative humidity conditions, that creates convenient conditions for the biofilms growth.

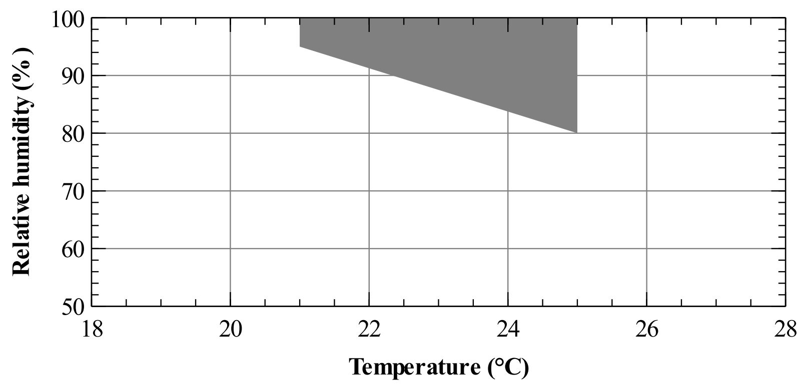

Figure 1. Optimal hygrothermal patterns for biofilm growth.

3 COMPUTATIONAL MODELING OF HYGROTHERMAL CONDITIONS

The distribution of moisture and temperature over the reference climatic year was estimated using one-dimensional modeling of coupled heat and moisture transport using a computer code HM Transport 2.0, which was developed at the Department of Materials Engineering and Chemistry, FCE CTU Prague (Kočí *et al.* 2018a). It works as a preprocessor for the general finite-element package SIFEL (Kruis *et al.* 2010). An advanced diffusion mathematical model was used for this purpose (Maděra *et al.* 2017). The balance equations of heat (Eq. (1)) and moisture (Eq. (2)) are formulated as

$$\rho_w \frac{\mathrm{d}\,w}{\mathrm{d}\,p_v}\frac{\partial p_v}{\partial t} = \mathrm{div}\left[\left(BD_w\rho_w \frac{\mathrm{d}\,w}{\mathrm{d}\,p_v} + A\delta_p\right)\mathrm{grad}\,p_v\right], \quad (1)$$

$$\frac{\mathrm{d}\,H}{\mathrm{d}\,T}\frac{\partial T}{\partial t} = \mathrm{div}\left(\lambda\,\mathrm{grad}\,T\right) + L_v\,\mathrm{div}\left[A\cdot\delta_p\,\mathrm{grad}(p_v)\right], \quad (2)$$

where following symbols stand for: ρ_w ($kg\cdot m^{-3}$) – water density, w ($m^3\cdot m^{-3}$) – water content, p_v (Pa) – partial pressure of water vapor in the air, t (s) – time, D_w ($m^2\cdot s^{-1}$) – moisture diffusivity, δ_p

(s) – water vapor permeability, H (J·m^{-3}) – enthalpy density, T (K) – temperature, λ (W·m^{-1}·K^{-1}) – thermal conductivity, L_v (J·kg^{-1}) – latent heat of evaporation of water. Ranging between 0 and 1, the variables A, B are transition coefficients that are applied to distinguish between the particular phases of water according to the current moisture content. This model has been successfully validated within previous studies (Maděra *et al.* 2017, Kočí *et al.* 2018a).

In order to study an effect of load bearing material on a susceptibility to biofilms growth, a wall made of three different materials was considered being provided with lime cement plaster (LCP) from both sides. The wall was assumed to be made of autoclaved aerated concrete (AAC), solid brick (SB) and sandstone (SS). These materials are supposed to cover a broad spectrum of load bearing materials used in these days: natural stones, modern materials with excellent thermal insulation properties or traditional materials. The details of the segment studied including parameters of the computational mesh are shown in Figure 2. The structure of the mesh is optimized, being formed by small segments on the boundaries or near material interfaces which makes it dense. On the other hand, large segments are used in the middle of each layer. Such a construction represents a compromise between the computing time and accuracy of results obtained. The list of material properties is summarized in Table 1 (Kočí *et al.* 2014, Kočí *et al.* 2016, Kočí *et al.* 2018b, Kočí *et al.* 2018c). All the data were obtained experimentally following the methodology proposed by Černý (2013).

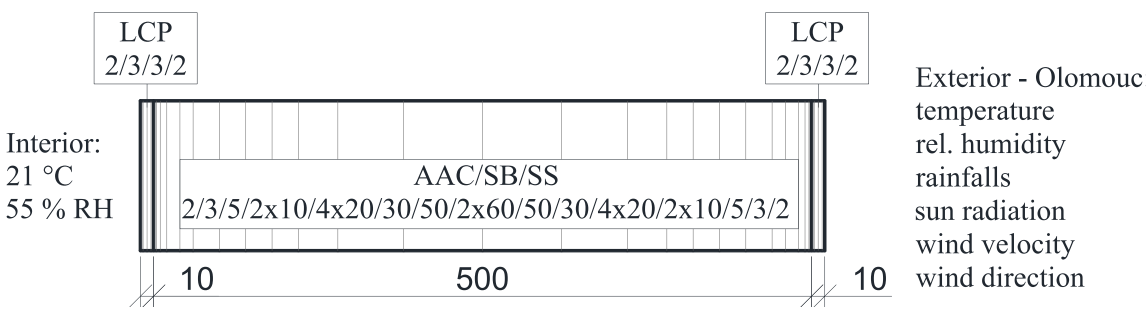

Figure 2. Scheme of analyzed wall.

Table 1. Material properties.

Parameter	AAC	SB	SS	LCP
Bulk density (kg·m^{-3})	304	1831	2076	1244
Open porosity (%)	87.6	27.9	22.8	49.8
Specific heat capacity (J·kg^{-1}·K^{-1})	1080	825 – 1254	694 – 1098	1054 – 1592
Water vapor diffusion resistance factor (-)	2.5 – 7.1	8.8 – 22.1	6.9 – 11.8	5.5 – 7.5
Thermal conductivity – dry state (W·m^{-1}·K^{-1})	0.080	0.590	2.100	0.296
Thermal conductivity – water saturated state (W·m^{-1}·K^{-1})	0.548	1.735	3.880	0.943
Moisture diffusivity (m^2·s^{-1})	8.80×10^{-9}	1.08×10^{-6}	7.92×10^{-7}	3.27×10^{-8}

The transport processes inside the studied detail can be initiated only after exposure to different boundary conditions. Therefore, dynamic climatic conditions in form of Olomouc's test reference year (ČSN ISO 15927-4 2005) were applied on the exterior side while constant conditions (21 °C, 55% of RH) were used on the interior side (ČSN 730540-2 2011). The selected weather data of the reference year is shown in Table 2. The simulations were run for five years. The results displayed are related to the last year of simulations. Corresponding to the time step selected, hourly values of relative humidity and temperature were obtained. Under these circumstances, the simulation of one assembly took approximately three hours.

Table 2. Selected weather data of the Olomouc's test reference year.

Parameter	**Temperature**					**Relative humidity**			**Rainfalls**
	Max	**Min**	**Avg**	**>30 °C**	**<0 °C**	**Avg**	**>90 %**	**<40 %**	
Value	34.1 °C	-13.9 °C	9.8°C	32 h	1261 h	76.04 %	2240 h	334 h	570.9 mm

4 RESULTS AND DISCUSSION

Using the above mentioned mathematical model and all the input parameters described, the hygrothermal performance across the segment studied was obtained. Since it was evaluated from the point of view of the biofilms growth conditions, the hygrothermal performance on the exterior surface was taken into account only.

As it was expected, the hygrothermal performance on the surface is not dependent on only a material of a plaster or boundary conditions, the load bearing material can affect it as well. Different material parameters, the storage ones in particular, and thus hygric and thermal function of load bearing materials can affect the performance of the whole envelope. In this light, computational modelling seems to be a powerful tool to reveal possible negative material combinations in advance.

Basically, there are two ways due to which material might slow down the biofilm growth: due to their good thermal insulating properties they can contribute to exterior surface temperature decrease below the optimal growth temperature or they can rapidly redistribute the liquid moisture absorbed from the environment and keep it low. Even if this is mainly the task of the exterior plaster, the load bearing material can contribute as well. The numbers of positive hours for the biofilm growth within the reference year are summarized in Table 3 and further discussed. Basically, it summarizes time, when temperature and moisture content (hygrothermal patterns) were in the optimal zone presented in Figure 1.

Table 3. Summary of optimal conditions for biofilm growth.

	AAC	**SB**	**SS**
Optimal conditions duration (h)	3	5	5

According to the results presented in Table 3, the best results were obtained when AAC was considered. This is connected to its excellent thermal insulating properties as the thermal conductivity is very low, reaching up to 0.080 $W \cdot m^{-1} \cdot K^{-1}$ in the dry state. A closer look on hygrothermal performance of the particular walls further reveals that it is mainly the thermal performance that makes the differences. Figure 3 depicts temperature and moisture profiles as of August 5, 17:00 which is a moment when convenient conditions were detected in case of SB a SS. It can be noticed the surface relative humidity is very similar, accounting for ~94.3% in all the cases, which yields a positive temperature threshold of 21.19 °C. However, while the surface temperature of AAC wall is only 20.98 °C, the surfaces of SB and SS walls reach 22.37 °C and 22.63 °C, respectively.

The number of hours with positive conditions for biofilms growth detected in this paper can be considered as very small. On the other hand, one must take into an account that the detail investigated is a standard wall without any other influencing factors such as increased moisture straining or shading. Furthermore, exposure to wind or sun radiation that is applied has positive effects on the biofilms growth elimination as it may contribute the hygrothermal patterns to be kept outside the positive zone. Such wall details are not prone to biodegradation even in real building practice since most damages can be found in buildings' plinths, attics or around gutters. Therefore, focusing on critical construction details that can exhibit an increased moisture straining is highly appreciated instead of simple walls only. Beside the above mentioned the cases considering north-oriented walls, shaded parts, or details around thermal bridges or water leakage should be included.

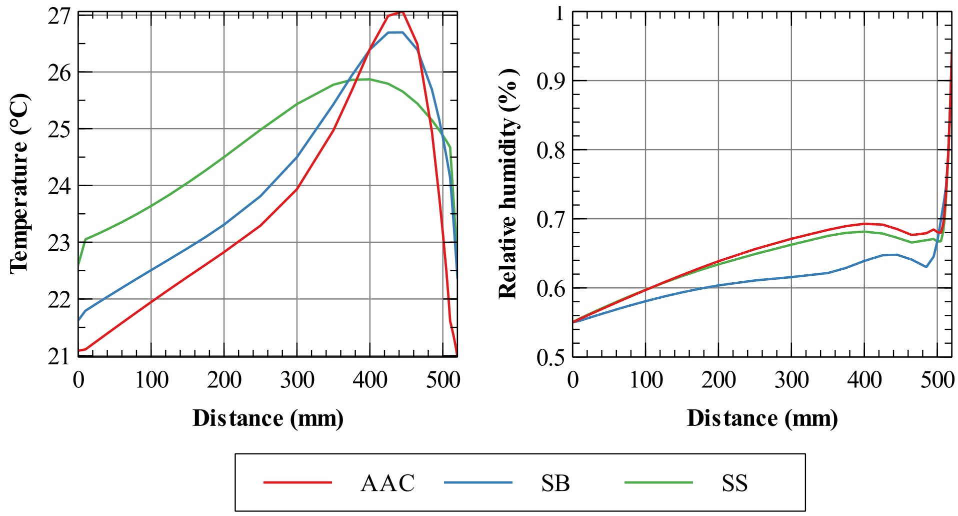

Figure 3. Hygric and moisture profiles as of August 5, 17:00.

5 CONCLUSIONS

An influence of load bearing materials on exterior surface conditions was studied in this paper by means of computational modeling of coupled heat and moisture transport. Main objective of the computations was to identify optimal hygrothermal conditions that might induce a biofilms growth. The wall segment was built of autoclaved aerated concrete, solid brick and sandstone, being provided with lime cement plaster. Such assemblies were exposed to dynamic climatic conditions in form of reference year of Olomouc, Czech Republic.

According to the results obtained, the load bearing material can also affect the surface conditions of the segment as it may influence the hygrothermal performance of the whole assemblies. It was concluded that thermal transport properties of the load bearing material play decisive role affecting the exterior surface temperature. From this point of view, the assembly made of autoclaved aerated concrete showed the best results. In this case only three positive hours during the reference year were counted which is lower by 40% when compared to brick and sandstone. Such behavior can be explained by low value of thermal conductivity of autoclaved aerated concrete that reduces the heat flux from the interior and thus prevent the exterior surface warming.

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