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Review

Algal colonization kinetics on roofing and façade tiles: Influence of physical parameters

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HIGHLIGHTS

- A liquid film of water was a main condition to induce algal growth.
- The roughness should be the most significant parameters in order to retain algae.
- In saturated conditions, the porosity boosts colonization by playing a role of water supply.
- The surface chemistry that could be considered as a second order parameter.

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ABSTRACT

Algal growth is responsible for aesthetic defects on roofing tiles. Accelerated water-streaming tests were done on different building materials. The results establish the ranges of porosity and roughness that can initiate the colonization under humid saturation. A smooth surface is then recommended to reduce the settlement. Experiments done on limestone and clay tiles demonstrate that coupling high porosity and rough surface should be banished to avoid any rapid algal colonization. However, the alkaline composition of concrete tiles can strongly affect the algal settlement, whatever their intrinsic porosity and roughness. Observations by Environmental Scanning Electron Microscopy show that calcite crystals could promote the settlement of algae on the surface.

Contents

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1. Introduction

Roofs and building façades (made of quarry, slate or concrete tiles) exposed to natural environments are subject to biological development, causing aesthetic degradations [15]. Visible microorganisms involved in biological settlement are first algae, followed by lichen and moss, respectively. In the last previous years, numerous observations on roof or façade tiles have shown that algae are ubiquitous and mainly responsible for the discoloration [5]. Species involved have been characterized [11] and belong to the two major classes encountered: *Cyanophyceae* and *Chlorophyceae*.

Kinetics of algal growth depends on environmental conditions and on material properties such as chemical composition, roughness, porosity, surface energy, pH [2,3,11]. Those main physical and chemical parameters characterize the concept of bioreceptivity, defined as the ability of a material to be colonized [17]. This concept is correlated with the content and the localization of liquid water, which is the main requirement for algal growth [18]. Several studies [10,22] indicate that a film of liquid water is necessary for the colonization with green algae, but incertitude exists about the localization of the available water (in the porous network and/or near the top-surface).

Some preventive treatments are currently performed to delay algal growth on tiles such as the use of water repellents and photo-catalytic TiO_2 inclusions [7]. Curative and preventive treatments, such as biocides [15], can be also applied to remove the colonization with algae [1,21,24]. However, according to new environmental issues, the definition of threshold parameters would offer new alternatives: the limitation of the use of chemical products and the optimization of the manufacturing process to protect roof or façade in an easier and cheaper way.

Because the first visible biological developments begin generally after a 1-year of natural exposure [2,11], the studies carried out on algal colonization require the implementation of accelerated tests. Several accelerated water-streaming tests have been developed in France for concrete substrates [4,12,14]. The main results have shown that the behavior of algae settlement in different moisture conditions is species-dependant. They have then established that roughness and porosity are the most influent parameters on algal growth. The assumption that a superficial film of liquid water is then sufficient to induce a perennial settlement seems to be relevant [10,22].

In order to study the influences of physical parameters, several reference tiles (made of porous sintered glass types or non-porous glass) have been initially exposed to a homemade accelerated water-streaming test. After recalling the experimental set-up and the characterization means (image analysis) carried out, kinetics of algal settlement on glass tiles are compared to those measured on the four types of tiles made of different building materials (limestone, clay, common pre-cast concrete and high-performance concrete, respectively).

2. Experimental

2.1. Test methods

2.1.1. Mercury intrusion porosimetry (MIP)

The glass and concrete tiles were investigated by the mercury intrusion porosimetry technique (Autopore IV 9500 from Micromeritics, USA) to assess the porous distribution (with breakthrough diameter) and the overall porosity [13,20,23,25]. The pressure range of the porosimeter was from sub ambient up to 400 MPa, covering the pore diameter range from about 360 μm to 3 nm. Tests were carried out on $10 \times 10 \times 10$ mm^3 samples cut from the core of the tiles. The samples were dried in an oven at 45 °C overnight before being tested.

2.1.2. Profilometry

The roughness was characterized by a SurPhase HS (from PhaseView, USA). This system couples spatial variation of the electromagnetic power with 3D shape of the illuminated object (on standard step height of 20 μm, the accuracy for step height measurement is 0.022 μm and the standard deviation (repeatability) is 0.014 μm). The arithmetic means (Ra) of the profile deviations from the mean line were calculated to compare the roughness of each kind of tile.

2.1.3. Environmental Scanning Electron Microscopy (ESEM)

Tiles made of concrete were characterized after algal colonization using a high-resolution field-effect gun digital scanning electron microscope (SEM FEG Quanta 400 from FEI Company, USA) with an accelerating voltage of 15 keV and a current intensity of 1 nA. The images were obtained in environmental mode (ESEM) that enables observations of hydrated and organic samples, such as microorganisms, assuring their integrity.

2.1.4. Image analysis

The characterization means used to measure algal growth on tiles have to be non-destructive. One of the easiest methods seemed to be image analysis whose effectiveness has been confirmed in previous studies [4,9,12]. The colonized area could be very low; a particular attention will be so given on image analysis to obtain the best accuracy. The photographs of samples were obtained using a Hewlett Packard Scanjet 8300 scanner. This method offered identical conditions of lighting, resolution and recording parameters.

2.1.4.1. Image analysis method. Quantification of the colonized area was done using two different image analysis methods. The first one, and the more used, was the threshold method [2,12] while the second one was the *k*-means method [2,17]. Since accuracy of those two methods has not been assessed in these previous studies, we review the two methods and propose in this paper a method to measure it.

2.1.4.2. Threshold method. The threshold method is based on a classical signal processing method of the low/high pass frequency filter. The threshold value can be estimated or calculated on the first image (provided on wet samples) without algal spots. However, the fact remained that the main difficulty is to determine the threshold value. Sometimes the threshold value is set by operators [9], and therefore accuracy of the method may be reconsidered. In this study, this value was calculated from the Y normalized histogram of initial images (images are decomposed along the Y vectors of CMYk color space). Assuming that the distribution of pixel coloration has a