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Characterization of biological stains on external concrete walls and influence of concrete as underlying material

A. Dubosc[a], G. Escadeillas[a,*], P.J. Blanc[b]

[a]*Laboratoire Matériaux et Durabilité des Constructions, INSA/UPS, 135 Avenue de Rangueil, 31077 Toulouse, France*
[b]*Laboratoire Biotechnologies-Bioprocédés, INSA, 31077 Toulouse, France*

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Abstract

Investigations were carried out on concrete walls stained by biological growth. Pieces of this material were removed down and observed using optical microscopy, low-vacuum scanning electron microscopy (LVSEM) and normal SEM. The results show that biological stains are due to two different kinds of microscopic algae, Chlorophyceae and Cyanophyceae, whose presence depends on the amount of moisture on the concrete wall. Accelerated laboratory tests of biological growth on mortar samples that were performed show that algal developments increase with the porosity of the underlying material. Thus, it seems that the use of dense, high-performance mortars can slow down or even inhibit microorganism growth. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Unsightly stains on external concrete walls cause loss of aesthetic beauty [1,2]. This type of staining is often due to biological growth, particularly at places where design features or maintenance faults result in frequent wetting of the surface [3,4]. Indeed, although fungi can colonise organic materials or internal painted walls, external stains on bare concrete are often due to the development of microscopic algae, especially when the supply of moisture and light are not limited [5–7]. Algae are phototrophic organisms, i.e., their energy source comes from daylight and their nutritive sources are mineral. They need constant moisture to develop but can resist dry periods [6]. Their presence usually leads to infestation by lichens and mosses after several years [3,5,6].

The characteristics of the substrate influence algal growth. Smooth surfaces are less affected than rough and porous ones; those, which retain water strongly, are the most seriously affected [6,8]. These findings are based on on-site visual observations and a few laboratory tests carried out to study the effects on growth of mortars with different types of porosity. Guillitte and Dreesen [9] tested various building materials (stone, bricks, mortars and concrete) under favourable biological conditions and observed that the bioreceptivity of the materials was highly variable and depended on their surface roughness, initial porosity and mineralogical nature. Ohshima et al. [10] also noted that under laboratory accelerated conditions, algal growth was affected by the equilibrium moisture content originating from the pore structure of mortar surface.

The aim of this research was to study the effects of underlying concrete characteristics on biological stain development using accelerated tests. Preliminary on-site investigations are described in this paper. Characterization of algal stains on walls was carried out by various microscopic means to demonstrate how biological soiling can be recognised through microscopy. An accelerated laboratory test was also performed to evaluate the effects of mortars with different porosity on algal colonisation.

2. Methods

2.1. On-site sampling

Several biologically stained walls in the city of Toulouse (south of France) and its outskirts were studied. Samples of

* Corresponding author. Tel.: +33-5-61-55-99-31; fax: +33-5-61-55-99-49.
E-mail address: gilles.escadeillas@insa-tlse.fr (G. Escadeillas).

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Table 1
Details of stains

Site	Stain colour	Algae class	Algae genera	Probable cause of staining
1	Black	Cyanophyceae	Gloeocapsa-Chroococcus	Facing the prevailing wind
2	Black	Cyanophyceae	Gloeocapsa-Chroococcus	Oriented to the prevailing wind
3	Green	Chlorophyceae	Microspora	High relative humidity zone
4	Green	Chlorophyceae	Chlorhormidium	Intermittent flow
5	Red	Chlorophyceae + Cyanophyceae	Trentepohlia-Gloeocapsa	Facing the prevailing wind

stains were scraped off and placed in small sterile bottles. One part was examined under the optical microscope; another, from a measured area, was quantified using the *chlorophyll a* measurement technique [12]; and the last part was cultivated on a nutrient medium to identify the species. Pieces of stained concrete were removed for video-microscopic, scanning electron microscopy (SEM) and ESEM observations. A preliminary characterization of the concrete surface was carried out, and the parameters of staining were determined (moisture conditions, surroundings, etc.).

2.2. Microscopic observations

Scraped samples of microorganisms were put in a drop of water and examined on slides with an optical microscope at a magnification of $\times 400$. An iodine test was carried out to detect the presence of starch, representative of the Chlorophyceae class. Algae and other organisms were identified this way.

Pieces of stained concrete were first examined under a video-microscope at a magnification of $\times 175$. Then, low-vacuum SEM (LVSEM) was used. LVSEM can be used to examine hydrated specimens, and unlike SEM, it does not require a high vacuum or sample pretreatment to make it conductive. The surface and cross-sections of the samples were observed to see interactions between the algal film and the underlying material. The same pieces of concrete were examined by SEM. The aim was to observe stains at very high magnifications. Once again, surface and cross-sections of the samples were observed.

2.3. Accelerated laboratory test methods

Mortar samples with four different water/cement ratios (0.38, 0.5, 0.6 and 0.7) were made. The cement used was an ordinary Portland cement. The aggregate was siliceous river sand. For the W/C 0.38 series, superplasticizer and densified silica fume were added. Three $50 \times 50 \times 10$ mm prisms were cast for each mortar mixture, and their cast surface was tested under conditions, which favoured biological growth. Samples were thin to evaluate the influence of the open porosity of the first centimetre on development.

The experiment was performed as follows. Samples of the four mortar series were exposed to intermittent sprinkling with deionized water enriched with minerals containing a mixture of pioneer colonising algal diaspores over a 2-month period on runoff surfaces tilted at 45°. This medium was raised from the bottom of the chamber to the watering device. Thus, a closed cycle was achieved.

The environmental conditions were as follows. Samples were incubated under lighting conditions of 2000 lx, 12 h/day with a ''daylight'' white fluorescent lamp. Another lamp lit the culture medium behind the sample rack. The temperature varied between 21 °C at ''night'' and 25 °C during the ''day.'' The relative humidity reached values of 95% at night and 80% during the day. Sprinkling of the solution took place for 3 h/day. Growth on the mortar samples was quantified after 8 weeks by measuring the area covered using image analysis. Although microorganisms increase their layer thickness as they grow, the area covered

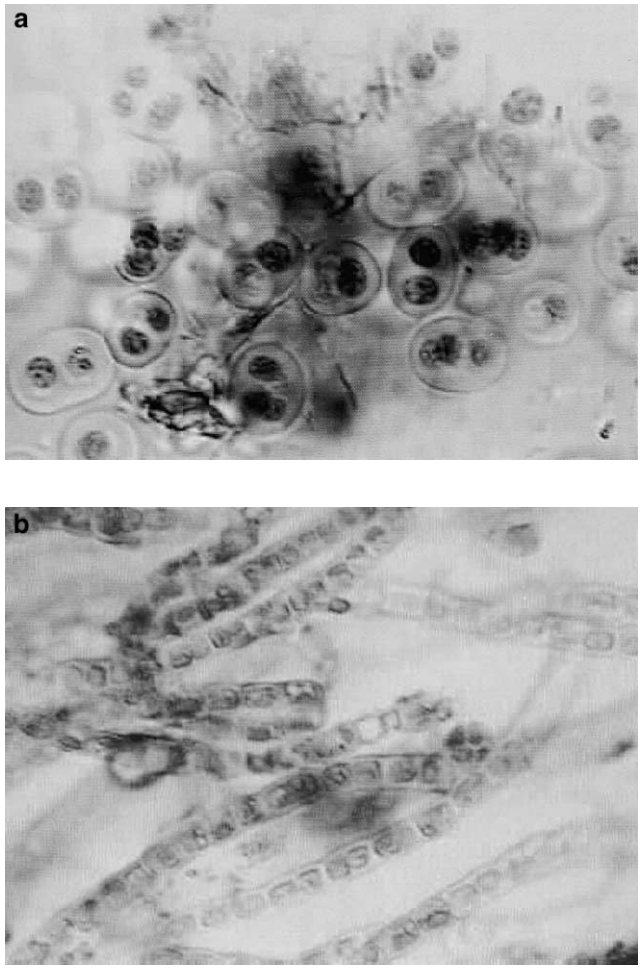

Fig. 1. Cyanophyceae from black stain ($\times 400$). Chlorophyceae from green stain ($\times 250$).

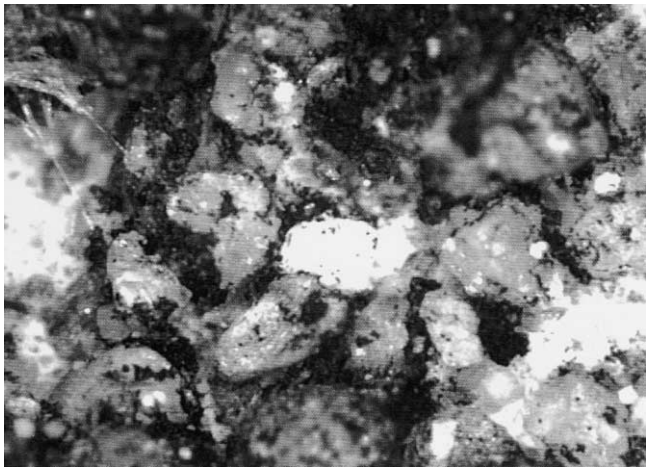

Fig. 2. Video-microscope micrograph, black stain (× 100).

is the most important factor for quantification of this aesthetic problem.

3. Results

3.1. Microbial identification of scraped stains

As shown in Table 1, all the visible stains investigated were due to algae. Two types were identified, depending on the staining colour. Cyanophyceae appeared as black stains, while Chlorophyceae formed green and red stains.

Optical micrographs of the two classes of algae from scraped samples are shown in Fig. 1. Cyanophyceae cells often develop inside a mucilage sheet. They grow on walls subjected to dry periods. These sheets retain water during rainfall and permit algae to survive during dryness. Chlorophyceae grow in areas subjected to constantly high moisture. Neither their cells have mucilage sheets nor can they resist dry conditions. Thus, green stains cover constantly wet walls.

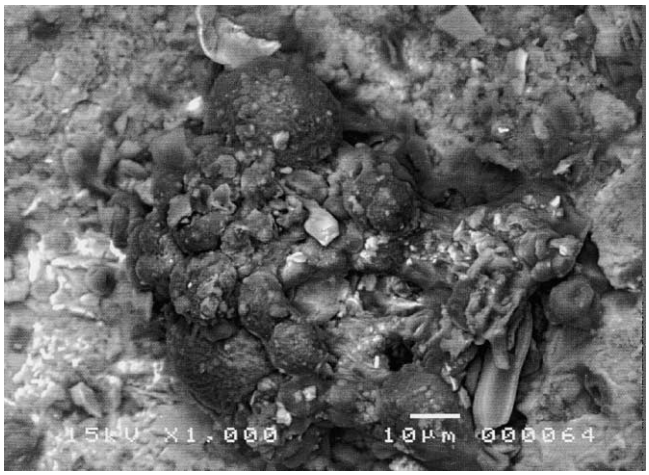

Fig. 3. LVSEM micrograph, black stain (× 1000).

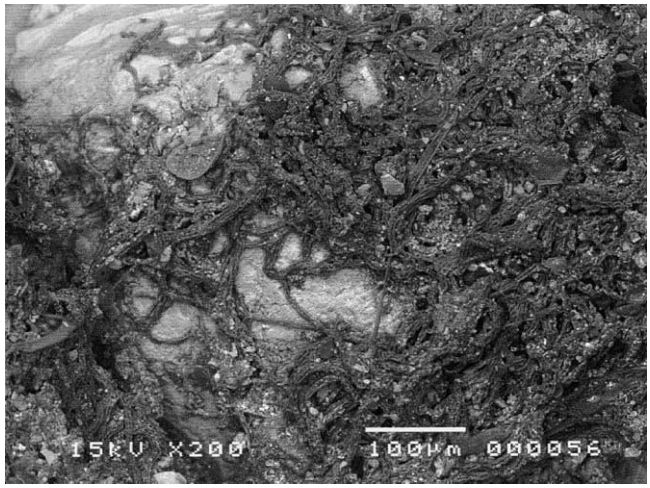

Fig. 4. LVSEM micrograph, green stain (× 200).

Algal genera identified in Table 1 are the same as those found in the literature from different countries like Ireland, Brazil and Singapore [5,7,11], signifying that these species are ubiquitous and their origin depends on environmental conditions.

Results of *chlorophyll a* quantification of scraped samples did not give authentic results because, on the one hand, scraping all the microorganisms off a defined area is impossible as they cling strongly to the surface and, on the other hand, this method is not very representative for stains with different kinds of algae [12]. Likewise, the culture on different nutrient media (organic and mineral) is not appropriate to determine the dominating organisms in stains because it favours the growth of no representative microorganisms like bacteria or fungi.

3.2. Characterization of stained concrete

A micrograph of a piece of concrete stained black is shown in Fig. 2. The black cover occurs on the cement paste

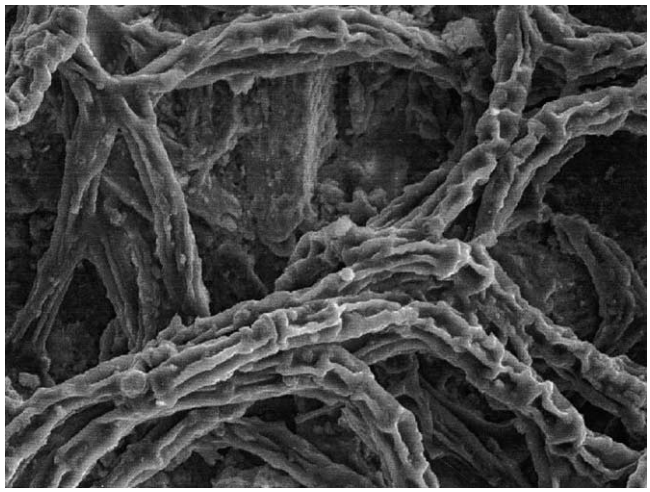

Fig. 5. SEM micrograph, green stain (× 1000).

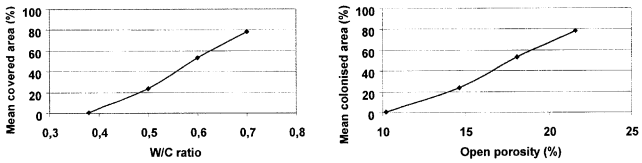

Fig. 6. Variation of the mean area colonised vs. W/C ratio (left) and open porosity (right) of the mortars.

around aggregates. It can be due to the higher porosity of the cement paste, which makes more water available for the organisms to grow. Biological shapes (unicellular or filamentous) were not visible at this magnification.

The same black stain, when examined at a higher magnification ($\times$ 1000) under LVSEM, showed unicellular shapes (Fig. 3). The cells were 10 μm across, like common unicellular Cyanophyceae. Mineral particles appeared to be hooked to the organisms. Observation ($\times$ 200) of a green-stained concrete sample showed obvious filamentous forms, probably Chlorophyceae cells, covering the surface (Fig. 4). Typically, such shapes are representative of biological colonisation.

The green-stained concrete sample under the SEM clearly showed Chlorophyceae filaments at a high magnification ($\times$ 1000, Fig. 5) but the filaments appeared to have dried out and stunted. This was probably due to the high-vacuum condition during carbon sputtering. Filamentous shapes however were evident. Observations of spherical Cyanophyceae cells showed both stunted and normal shapes.

3.3. Accelerated test results

After 8 weeks in conditions favourable for the growth of algae, the colonised surfaces of the four mortar series were assessed. The variation of the mean area colonised depending on the water/cement ratio and on the open porosity of the four mortar series are shown in Fig. 6.

Algal colonisation increased with W/C ratio and porosity, i.e., high porosity mortars were more infested by microorganisms. Indeed, these samples retain more water during flow, and thus, their surface remains damp longer. Only the W/C = 0.38 series with silica fume remained clean, without algal stains.

4. Discussion

Observations of concrete show the specific areas where stains are likely to develop, cement paste all around aggregates. ESEM at a high magnification ($\times$ 1000) is necessary to identify small spherical cellular shapes (like 10 μm Cyanophyceae cells). SEM observations give clear images, but the high vacuum needed can cause a change in the cell shapes. Transmitted light optical microscopy of scraped samples is required to identify algal species, for observing their cell components, such as chloroplasts of Chlorophyceae cells and mucilage sheets of Cyanophyceae cells. These shapes are readily recognisable in biological stains on concrete. The technique of culturing scraped samples of stains to identify the dominant organisms often leads to the growth of microorganisms present only in small amounts in stains. The microscopic method is more appropriate for the identification of stain components

On-site observations and microscopic observations demonstrate that algal growth depends on humidity conditions and preferentially take place on the more porous surfaces. Chlorophyceae green and red stains develop in steadily humid conditions (frequent water flow and high relative humidity), while Cyanophyceae black stains are observed on concrete walls subject to dry periods. Their cells can resist dryness due to the mucilaginous sheets, which retain water during wet periods. ESEM shows that mineral particles are often attached to the sheets. This confirms that algae cover can accelerate dust deposition [6].

Laboratory tests confirm the importance of humidity for enhanced algal growth rates and the significant effects of the characteristics of the underlying material. In our test, the effects of mortar porosity on growth are obvious. Higher porosity leads to more persistent dampness during the dry phase. Therefore, only the use of high-performance mortar at a low W/C can inhibit algal development in these accelerated conditions.

5. Conclusions

Microscopic tools are useful for characterising the origin of biological stains on concrete and identifying preferential growth areas. Accelerated laboratory tests confirm the effect of mortar characteristics on algal development. Particularly noteworthy is porosity, which changes the duration of surface wetness during dry periods. Investigations on the effects of mineral composition of substrate and on concrete deterioration due to acid generation from algal growth are in progress and will be presented later.

Acknowledgments

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References

[1] D.D. Higgins, Removal of stains and growths from concrete, Appearance Matters 5 (1982) 1–11.
[2] L.G.W. Verhoef. Soiling and cleaning of building façades, RILEM Technical Committee 62 Report, 1986.
[3] Control of lichens, moulds and similar growths, BRE Dig. 370 (1992) 1–4.

[4] A. Le Borgne, C. Lanos, M. Trigalleau, Le bâtiment face à sa microflore, (Editions ARIA-INSA, Reims), 1994.
[5] Y.C. Wee, K.B. Lee, Proliferation of algae on surfaces of buildings in Singapore, Int. Biodeterior. Bull. 16 (4) (1980) 113–117.
[6] F. Grossin, P. Dupuy, Méthode simplifiée de détermination des constituants des salissures, International RILEM Symposium, Deterioration and Protection of Stone Monuments, Paris, 1978.
[7] N.M. Ryan, Algal growth on cementitious surfaces, Pilot study of the National Institute for Physical Planning and Construction Research, Dublin, 1983.
[8] P. Whiteley, The occurrence and control of moulds and algae on paints, J. Oil Col. Assoc. 56 (1973) 382–387.
[9] O. Guillitte, R. Dreesen, Laboratory chamber studies and petrographical analysis as bioreceptivity assessment tools of building materials, Sci. Total Environ. 167 (1995) 365–374.
[10] A. Ohshima, I. Matsui, N. Yuasa, Y. Henmi, A study on growth of fungus and algae on mortar, Trans. Jpn. Concr. Inst. 21 (1999) 173–178.
[11] C.C. Gaylarde, P.M. Gaylarde, Biodeterioration of painted walls and its control, International RILEM Workshop on Microbial Impacts on Building Materials, Sao Paulo, 2000.
[12] A. Dubosc, G. Escadeillas, P.J. Blanc, Etude du développement de salissures d'origine biologique sur des parements en béton brut: mise au point d'un essai de laboratoire, 3ème Congrès Universitaire du Génie Civil, Lyon, 2000.