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Evaluation of natural colonisation of cementitious materials: Effect of bioreceptivity and environmental conditions

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HIGHLIGHTS

- Environment seems to have greater impact than intrinsic properties of the material.
- Extra measures are indispensable for a rapid development of biological growth.
- The environment and the relationships between organisms should be considered.

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ABSTRACT

Incorporation of living organisms, such as photosynthetic organisms, on the structure envelope has become a priority in the area of architecture and construction due to aesthetical, economic and ecological advantages. Important research efforts are made to achieve further improvements, such as for the development of cementitious materials with an enhanced bioreceptivity to stimulate biological growth. Previously, the study of the bioreceptivity of cementitious materials has been carried out mainly under laboratory conditions although field-scale experiments may present different results.

This work aims at analysing the colonisation of cementitious materials with different levels of bioreceptivity by placing them in three different environmental conditions. Specimens did not present visual colonisation, which indicates that environmental conditions have a greater impact than intrinsic properties of the material at this stage. Therefore, it appears that in addition to an optimized bioreceptivity of the concrete (i.e., composition, porosity and roughness), extra measures are indispensable for a rapid development of biological growth on concrete surfaces. An analysis of the colonisation in terms of genus and quantity of the most representative microorganisms found on the specimens for each location was carried out and related to weather conditions, such as monthly average temperature and total precipitation, and air quality in terms of NO_x, SO_2, CO and O_3. OPC-based specimens presented a higher colonisation regarding both biodiversity and quantity. However, results obtained in a previous experimental programme under laboratory conditions suggested a higher suitability of Magnesium Phosphate Cement-based (MPC-based) specimens for algal growth. Consequently, carefully considering the environment and the relationships between the different organisms present in an environment is vital for successfully using a cementitious material as a substrate for biological growth.

1. Introduction

Nowadays, two major technologies are used to create vegetated wall surfaces, i.e., systems rooted in the ground and systems rooted in artificial substrates. The first group refers mainly to the use of climber plants with or without supporting systems. In contrast, the second group is characterised by its dependence on irrigation systems and addition of nutrients to the substrate (Perini et al., 2011). Both systems suffer from high investment and maintenance costs (Pérez Luque, 2010). A cheaper alternative would be to stimulate the development of colourful patinas of biological origin on the surface of building materials.

As concrete is one of the most used building materials in cities around the world, it represents an eligible substrate for development of green facades. Ordinary Portland cement, however, is not a feasible material for the rapid development of a biological patina. The high alkalinity (pH of about 12) and rather low porosity make it a material with a low bioreceptivity. Biological colonisation only occurs once the pH has sufficiently dropped (pH of about 9–10), due to reaction of the cement

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Table 1
Specimens' composition.

Specimens	Composition	Compressive strength (MPa) (n = 6)	Porosity (%)	Roughness R_a (μm) (n = 12)	pH
Pa40-1C	Sand 0/2 mm a:c:w[a] = 4.41:1:0.4	15.83 ± 0.7	22.97	0.03 ± 0.00	≈9
Pa60-1.75C	Sand 0/2 mm a:c:w[a] = 3.22:1:0.6	46.81 ± 1.1	12.27	0.03 ± 0.01	
PA30-1C	Sand 2/4 mm a:c:w[a] = 3.8:1:0.3	27.52 ± 2.0	10.60	0.16 ± 0.02	
Ma20-0.75C	Sand 0/2 mm a:c:w[b] = 4.81:1:0.2	9.82 ± 0.1	18.20	0.04 ± 0.00	6.7
Ma28-1C	Sand 0/2 mm a:c:w[b] = 4.03:1: 0.28	24.45 ± 1.4	2.47	0.06 ± 0.00	
MA15-0.5C	Sand 2/4 mm a:c:w[b] = 6.6:1:0.15	9.18 ± 0.8	13.15	0.15 ± 0.01	

[a] CEM I 52.5R.
[b] Cement made by $NH_4H_2PO_4$, MgO and borax. $NH_4H_2PO_4$:MgO ratio = 1:1.75 and the addition of borax amounted to 6% by weight of the sum of $NH_4H_2PO_4$ and MgO weights; a:c:w is the ratio aggregates:cement:water; n is the number of replicates. Labels of specimens make reference to the binder (P: OPC; M: MPC), aggregate size (a: 0/2 mm; A: 2/4 mm), w/c ratio (e.g.,: 20 means w/c = 0.2 and 60 0.6), cement paste content (factor multiplying the minimum amount of cement paste, C, needed to join all the aggregate particles) (Klein, 2012).

matrix with atmospheric carbon dioxide, a process known as carbonation (Taylor, 1990). Ordinary Portland cement, however, is not the only binder used in construction. Cement with fly ash or silica fume addition present lower concentration of alkali and hydroxyl ions. Moreover, the aforementioned reduction would depend on the nature of the addition, the level of cement replacement, the alkali content of the cement and the age (Shehata et al., 1999; Erdem and Kirca, 2008).

At UPC (Barcelona, Spain), we have developed a multi-layered concrete panel for the development of green facades. This patented material is composed of four layers (Manso et al., 2014c). The first layer consists of conventional concrete and is responsible for the structural function of the panel. The main function of the second layer is to protect the first layer from ingress of water and noxious substances. Furthermore, it acts as a bond layer between the inner and outer layer. The function of the third layer is to stimulate the development of the biological patina. It represents an anchorage site for airborne microorganisms and a niche for microbial growth. Finally, the fourth and last layer is a discontinuous one in order to allow different designs of the surface. Exit of water is then redirected to the areas without this fourth layer, promoting better local conditions for colonising organisms.

In our previous study, we have screened several mortar formulations for their effectiveness as a substrate for biological growth (Manso et al., 2014b). Six different mortar designs were subjected to an accelerated algal fouling test. Main results extracted from this work were two; first, chemical intrinsic properties seemed to have more influence than physical ones under laboratory conditions and, second, Magnesium Phosphate Cement (MPC) appeared to be the most promising binder for the third layer of the multi-layered concrete panel.

Numerous research groups have been investigating natural colonisation of building materials. Studies mainly focus on the identification of the organisms on those surfaces, how to prevent their colonisation by means of the development of surficial treatments or methodologies of evaluation. For instance, Gaylarde and Gaylarde (2005) identified *Chlorophyceae* and *Cyanophyceae* as the most prevalent microorganisms found, where algal growth depends on humidity and porosity of the material and *Cyanophyceae* was mainly observed on concrete walls subjected to dry periods. De Muynck et al. (2009) compared different strategies for the prevention of algal fouling on two types of concrete and stated the performance of the surface treatments is dependent on the bioreceptivity of the concrete. Prieto et al. (2005) compared three different methodologies of biofilm quantification on stone: quantification of chlorophyll *a*, determination of fluorescein diacetate hydrolysis and determination of the total colour difference. The authors concluded that differences in colour can be used since it is statistically robust, easy, quick, non-destructive and can be used in situ and on site.

The use of accelerated laboratory tests is common when evaluating the intrinsic properties of a material (Guillitte and Dreesen, 1995; Dubosc et al., 2001; Escadeillas et al., 2007; De Muynck et al., 2009; Tran et al., 2012). However, colonisation of materials by living organisms depends not only on the bioreceptivity of the material but also on the climate conditions and the organisms present in the environment (Guillitte, 1995). Therefore, the necessity of field-scale experiments has gained more interest when studying biofouling of cementitious materials, although only few publications presented field-scale results. For instance, Tran et al. (2014) stated no correlation between laboratory and field-scale tests should be done due to dissimilarities between those two experimental scales. The authors suggested the necessity of modifying laboratory accelerated tests to approach the configuration to a real situation.

The aim of this research is evaluating different cementitious materials' designs to stimulate biological growth under different environmental conditions. For this purpose, a comparison between three

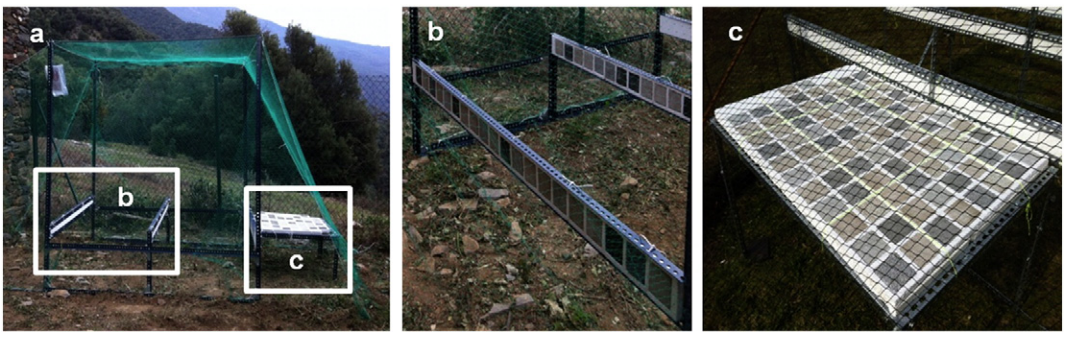

Fig. 1. Setup of specimens exposed to environmental conditions: (a) General view, (b) vertical specimens and (c) horizontal specimens.