International Biodeterioration & Biodegradation 95 (2014) 332–337

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

journal homepage: www.elsevier.com/locate/ibiod

Fungal and phototroph growth on fiber cement roofs and its influence on solar reflectance in a tropical climate

Márcia Aiko Shirakawa [a,*], Ana Paula Werle [a], Christine C. Gaylarde [a,b], Kai Loh [a], Vanderley M. John [a]

[a] Escola Politécnica, Departamento de Engenharia de Construção Civil, Universidade de São Paulo, São Paulo, SP, Brazil
[b] Univ. Oklahoma, Dept. Microbiology and Plant Biology, Norman, OK, USA

ARTICLE INFO

Article history:
Received 13 September 2013
Received in revised form
29 November 2013
Accepted 3 December 2013
Available online 15 January 2014

Keywords:
Biofilms
Fiber cement
Phototrophs
Reflectance
Roof tiles
Soiling

ABSTRACT

The materials used on roofs are mainly responsible for the reflection of the incident sunlight and absorption of heat at these surfaces. We investigated the occurrence of fungi and phototrophs, as well as determining the change in color (as L*), solar reflectance and thermal emittance of fiber cement exposed for 5 years in Pirassununga, a rural town in tropical Brazil. Considerable discoloration on the upper, exposed surface was shown to be related to high phototroph (especially cyanobacterial) colonization and reduction in reflectance. The large numbers of fungi detected on the lower, protected surface produced little color change and no reduction in reflectance. Thermal emittance was slightly, though significantly, reduced on the upper surface. The results indicate that, under conditions at this site, after 5 years exposure, phototrophs are more important than fungi in the reduction of reflectance at the exposed surface of fiber cement. This has important implications for cool roofing technology.

1. Introduction

Unsuitable roofing materials can cause raised internal temperatures and, where many such buildings are located in a relatively small area (in urban locations), this can result in large temperature differences between this and neighboring areas, the so-called urban heat island (UHI) effect (Ihara et al., 2008).

Roofs receive up to 95% of the incident radiation (Suehrcke et al., 2008) and the maintenance of reflectivity of these surfaces can be extremely important, especially in low-income (non-air-conditioned) buildings. Roof tiles in low income Brazilian homes are frequently made of fiber cement, with 250 million m^2/year of fiber cement tiles, representing 50% of new low-income buildings (Martins, 2012), being used. The material is easy to handle, low cost and widely used in light construction, economic housing and rural buildings for animals. Extreme discomfort can occur in the hot summer months, however, and a possible low-cost answer is the use of "cool" coatings.

High solar reflective ("cool") coatings on roofs can mitigate UHI, improve thermal comfort in buildings during the hot season and reduce energy required for cooling in those buildings with air conditioning. The use of such coatings is a financially accessible and easy-to-use technique that contributes to energy efficiency and thermal comfort of low-income buildings (Synnefa et al., 2007). "Cool roofs" are characterized by high http://heatisland.lbl.gov/glossary/term/16 solar reflectance (SR) and thermal emittance (TE); that is, as well as reflecting the incident sunlight, they radiate the heat absorbed by the roof and transferred to the building and surrounding air. The replacement of a common coating by a high reflective coating can provide a reduction of 1.2–3.3 °C in homes that do not use air conditioning (Synnefa et al., 2007). In air-conditioned buildings it is estimated to reduce energy requirements in the peak energy period by 11–27%, depending on the climate (Synnefa et al., 2007).

Maintenance of roofing reflectance is, however, a challenge. The deposition of particles, (pollution or microbial growth) results in discoloration and changes in reflectance (Berdahl et al., 2008). The nature, and not merely amount, of the deposits influences the change in reflectance. Elemental carbon, a product of incomplete combustion, is one of the most effective particles in reducing reflectance (Berdahl et al., 2002). These authors did not, however, consider carbon derived from microbial growth or other sources of

* Corresponding author.
E-mail addresses: shirakaw@usp.br, marcia.shirakawa@yahoo.com.br (M. A. Shirakawa).

0964-8305/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ibiod.2013.12.003

organic matter, and the performance of cool surfaces over time certainly depends on the quantity, diversity and speed of microbial growth. In all cases, the nature and quantity of material deposited on the surface depends on the environment, including proximity to urban or rural areas, nearby industries, local topography, weather, etc. (Cheng et al., 2012).

We exposed fiber cement to the aggressive natural environment in a rural part of São Paulo State, Brazil, for 5 years, following the non-laboratory conditions shown by Gladis et al. (2011) to be fundamental for biodeterioration testing. This paper discusses the changes observed in solar reflectance, thermal emittance and microbial colonization of the material in this time.

2. Materials and methods

2.1. Fiber cement tile

The large, corrugated fiber cement tile (1.83 × 1.10 m × 8 mm) was produced by the Hatschek process (Isaia, 2007). This consists of overlaying and compressing various layers of the material, a homogenous suspension of cement, additives, minerals and reinforcing fibers of polyvinyl alcohol (PVA) and cellulose that is passed through cylinders in a tank. The paste is sucked into the cylinders, where water is removed and layers of approx. 1 mm thickness are formed. These layers are pressed together before drying.

2.2. Exposure

The fiber cement tile was submitted to natural aging for 5 years (07/2006–11/2011), in the town of Pirassununga (−21° 57′ 33.34″ S, −47° 27′ 7.78″ W), São Paulo, southeast Brazil. The upper surface was exposed to the sky and the lower surface was protected from rain and sun. Pirassununga is located in a rural area of São Paulo State; average minimum and maximum temperatures are around 11 °C and 33 °C, respectively, and average annual rainfall is 167.7 mm.

2.3. Microbiological evaluation after 5 years' exposure

2.3.1. Fungi

In the laboratory, sterile toothbrushes were used to collect samples from 10 flat areas, each of 5 cm diameter, on each side of the tile (Tanaca et al., 2011). Each area was rubbed 10 times with the brush in a circular movement and the brush was then immersed in 10 ml sterile saline (0.85% NaCl). After shaking for 15 min (Vortex Agitator AP56, Phoenix, USA), tubes were placed in an ultra-sonic bath for 10 min. The liquid was then inoculated onto Sabouraud Dextrose Agar (Acumedia) and Dichloran Glycerol Agar Base (DG18, Acumedia) and incubated at 25 °C for 72 h.

2.3.2. Phototrophs

Twelve samples from the upper and lower surfaces were collected from the tile using the adhesive tape method described by Shirakawa et al. (2002). They were placed on modified KNOP's agar (Gaylarde and Gaylarde, 2005) and incubated in natural light. After 40 days, the adhesive strips were removed from the culture medium and strips and underlying agar examined by optical microscopy.

2.4. Physical measurements

2.4.1. Solar reflectance

Reflectance measurements were made using a *Solar Spectrum Reflectometer – model SSR – ER Version 6.4* (DT&S Devices and Services Company) and standard method ASTM C1549 (ASTM, 2009). The method was chosen as that recommended by the US Cool Roof Rating Council (CRRC-1 STANDARD, 2010), the organization responsible for the certification of cool products in the U.S.A., and a methodological reference for validation of products with the American Standards (Akbari et al., 2008). 50 reflectance determinations (2.5 cm diameter each) on the upper surface and 50 on the lower surface were made, over flat sections of the tile.

2.4.2. Thermal emittance

Thermal emittance was evaluated with the *Emissometer Model AE1* (DT&S Devices and Services Company). ASTM C1371-04 (1997), slide method was used. The Slide Method was adopted since the tile was very large. 30 determinations were performed over each of the upper and lower surfaces.

2.4.3. Color changes

We used the BYK Gardner 45°/0°, whose coordinates are based on the system of the International Commission for Illumination (CIE) L* a* b*, where: L* represents the black (0) to white (100) gradient, a* measures negative (green) to positive (red) values, b* measures negative (blue) to positive (yellow) values. The study focused on the black and white coordinates, i.e., measurements of L*. Fifty random samples were taken from each surface.

2.5. Statistical analysis

One-way ANOVA (analysis of variance) was used to evaluate the results using the program Statistica 11.

3. Results and discussion

The upper surface of the tile was considerably discolored after 5 years' exposure to the environment in Pirassununga, while the lower, protected surface remained much cleaner (Fig. 1a and b).

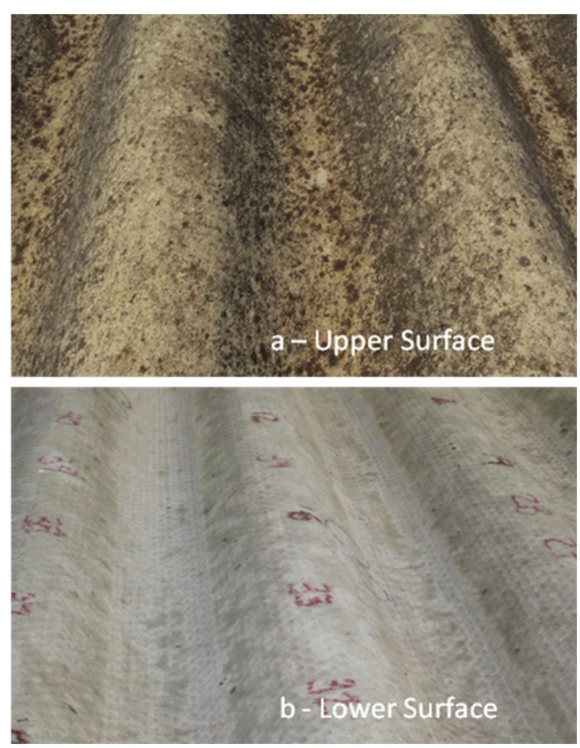

Fig. 1. Fiber cement tile after 5 years of natural exposure in Pirassununga; upper surface of the tile (a); lower surface (b).