Construction and Building Materials 26 (2012) 516–526

Contents lists available at ScienceDirect

Construction and Building Materials

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

Understanding the long-term effects of environmental exposure on roof reflectance in California

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ARTICLE INFO

Article history:
Received 30 July 2010
Received in revised form 13 June 2011
Accepted 18 June 2011
Available online 20 July 2011

Keywords:
Absorption
Aerosol
Building envelop
Cool-pigmented roof
Principal component analysis
Reflectance
Soot

ABSTRACT

Contaminants from cool-pigmented roof samples exposed at seven California sites were analyzed for elements and carbons to identify those that degrade or enhance solar reflectance. The losses in solar reflectance varied by site and the color of the sample. The least reflectance drop was observed in the alpine climate, while the largest drop occurred in sites near urban development. The change of reflectance appears cyclical with the onset of seasons having more rainfall. A deposition model suggests that chromium ranks first, iron second, and elemental carbon third in importance to soil light absorption.

1. Introduction

The long-term benefits of cool pigmented roofing systems [1] can be compromised if a significant loss in solar reflectance occurs during the first few years of service life. Ultraviolet radiation, atmospheric pollution, microbial growths, acid rain, temperature cycling caused by sunlight and sudden thunderstorms, moisture penetration, condensation, wind, hail, and freezing and thawing are all thought to contribute to the loss of a roof's solar reflectance [2]. Refs. [3,4] showed that in moderate to predominantly hot climates, an exterior roof surface with a high solar reflectance and high thermal emittance will reduce the exterior temperature and produce savings in comfort cooling. For predominantly heating-load climates, surfaces with moderate reflectance but low infrared emittance save in comfort heating. Determining the effects of climatic soiling on the solar reflectance and infrared emittance of cool color roofs is therefore very important for developing realistic claims of the net energy savings (cooling energy savings less heating penalty). Field data reported by Miller et al. [5] suggests that the loss of roof reflectance is due to dust load and or biomass accumulation, which in turn is modulated by the climatic conditions. Biomass may be due to the growth of fungi and/or mold species that were transported by airborne particulate matter blown by the wind. Deposition of atmospheric particles and moisture accumulation on the roof provide suitable conditions for the colonization of the microbes.

It is plausible that the aged solar reflectance of roofs is affected by many factors including atmospheric deposition of soot particles and dusts (e.g., dirt, road dust, and soil particles) [2]. To investigate the issues in depth, characterization of the chemical and physical attributes of the deposited particles was conducted on roof samples collected from the diverse climates of the state of California. Results published by Berdahl et al. [6] indicate "the long-term change of solar reflectance appears to be determined by the ability of deposited soot to adhere to the roof, resisting washout by rain." Samples studied were bare metal and polyvinyl chloride (PVC) roofing weathered for 18 years. Berdahl et al. [6] attributed soot, also known as black carbon or elemental carbon, to be the primary cause of long-term reflectance loss. Other potentially important light absorbing particles are iron-containing minerals such as hematite.

The objectives of this paper are (1) document the drop in solar reflectance and the change in thermal emittance for roof products having cool color pigments, (2) characterize the particulate matter deposited on roof samples of different materials, (3) establish the relationship between the deposited particulate matter and reduction of solar reflectance, and (4) quantify the contributions of the chemical composition of the particulate matter on the enhancement or loss of solar reflectance on a roof material.

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doi:10.1016/j.conbuildmat.2011.06.052

2. Materials and methods

2.1. Weathering sites in California

Seven sites in the diverse climates of California (Table 1) were selected for exposing painted metal, clay and concrete tile roof products with and without cool color pigments. The California population is expanding rapidly in the Central Valley and around the LA basin, and the sites with Custom-Bilt (Sacramento) and Elk (Shafter) capture the effects of weather, urban pollution and the expanding population. Samples were also exposed near weather stations maintained by the California Irrigation Management Information System (CIMIS). Sites in McArthur and El Centro, CA. were selected for acquiring exposure data in the more extreme climates. McArthur is located in the moderate alpine climate of northern California (climate zone 16); El Centro is in the extremely hot desert climate of southern California bordering the Arizona state line (climate zone 15). Table 2 locates each weathering site and provides the closest CIMIS station to each weathering site. Solar reflectance (SR) of the new and aged samples is also provided in Table 2 for the samples used for elemental contaminant determinations.

2.2. Exposure racks

All roof samples were installed in exposure rack assemblies, which are 1.68-m high by 2.74-m long, and divided into three sub-frames having respective slopes of 5.08-, 10.16- and 20.32-cm of rise per 30.48-cm of run (i.e., slopes of 9.5°, 18.4° and 33.7°). Each sub-frame can hold two sub-assemblies that are designed to have 6 rows of samples with 86.36-cm of usable space in each row. Sample size is 8.89-cm by 8.89-cm, a size that LBNL's spectrophotometer (Perkin–Elmer 900) can easily accommodate for measuring the solar reflectance at discrete wavelengths. Finally all exposure rack assemblies were oriented facing south for full exposure to natural sunlight and weathering (Fig. 1).

2.3. Instruments

A Device and Services solar spectrum reflectometer was used to measure the solar reflectance (total hemispherical reflectance over spectrum of sun's energy) of the roof samples. The device uses a tungsten halogen lamp to diffusely illuminate a sample. Four detectors, each fitted with differently colored filters, measure the reflected light in different wavelength ranges. The four signals are weighted in appropriate proportions to yield the solar reflectance. The device was proven accurate to within ±0.003 units [7] through validation against the ASTM E-903 method [8]. However, because the cool pigmented roof products exhibit high infrared reflectance, some of the field samples were measured at LBNL using their spectrophotometer to validate the portable Device and Services reflectometer. The average absolute difference between the portable reflectometer and the spectrophotometer was about 0.02 points of reflectance with the spectrophotometer consistently reading lower than the reflectometer.

The impact of emittance on roof temperature is as important as that of reflectance. A portable Device and Services emissometer was used to measure the thermal emittance using the procedures in ASTM C-1371 [9]. The device has a thermopile radiation detector, which is heated to 82.2 °C (180 °F). The detector has two high- and two low- elements and is designed to respond only to radiation heat transfer between itself and the sample. Because the device is comparative

Table 1
Weathering sites for exposing roof products.

Site ID	City	County	CIMIS ID	Latitude	Longitude	Climate zone	Mount
RS01	El Centro	Imperial	87	32°48′24″N	115°26′46″W	15	Ground
RS02	Corona	Riverside	44	33°57′54″N	117°20′08″W	10	Ground
RSO3	Colton	San Bernadino	44	33°57′54″N	117°20′08″W	10	Roof
RS04	Shafter	Kern	5	35°31′59″N	119°16′52″W	13	Ground
RSO5	Richmond	Contra Costa	157	37°59′30″N	122°28′12″W	3	Roof
RS06	Sacramento	Sacramento	131 & 155	38°35′58″N	121°32′25″W	12	Roof
RS07	McArthur	Shasta	43	41°03′53″N	121°27′16″W	16	Ground

Note: The last column "Mount" indicates the mounting location of a sample rack, either on the roof or on the ground.

Table 2
Sample identifications and solar reflectance after 1.63 and 4.06 years of exposure.

	El Centro (RS01)	Corona (RS02)	Colton (RS03)	Shafter (RS04)	Richmond (RS05)	Sacramento (RS06)	McArthur (RS07)
Samples for element study	Gray Artie concrete tile	Gray Artie concrete tile	PVDF metal charcoal gray	PVDF metal rawhide	PVDF metal rawhide	Gray Artie concrete tile	PVDF metal rawhide
Sample ID	976	676	517,518,519	704, 705, 706, 707	404,406	378	805,806
Sample area (m)	7.903E−03	7.903E−03	2.371E−02	3.161E−02	1.581E−02	7.903E−03	1.581E−02
SR initial	0.265	0.252	0.308	0.571	0.569	0.269	0.570
SR after 1.63 years	0.275	0.233	0.297	0.524	0.545	0.248	0.547
Samples for biomass study	PVDF metal hartford green	PVDF metal charcoal gray	Gray Artie concrete tile	Buff blend clay tile	PVDF metal rawhide	Brown Artie concrete tile	PVDF metal rawhide
Sample ID	920,921,922,923	616	576	779,780	405	372	804,807
Sample area (m^2)	3.161E−02	7.903E−03	7.903E−03	1.581E−02	7.903E−03	7.903E−03	1.581E−02
SR aged	0.272	0.309	0.246	0.527	0.569	0.261	0.571
SR after 1.63 years	0.277	0.297	0.241	0.484	0.544	0.254	0.549
Samples for element study	PVDF Metal Red brick	PVDF Metal hartford green	PVDF Metal slate blue	MCA Clay tile white buff	PVDF Metal rawhide	PVDF Metal charcoal gray	PVDF Metal slate blue
Sample ID	912–915	620–623	508–511	728–730	407	316–319	808–811
Sample area (m^2)	3.161E−02	3.161E−02	3.161E−02	2.37E−02	7.90E−03	3.161E−02	3.161E−02
SR initial	0.374	0.272	0.283	0.636	0.440	0.308	0.282
SR after 4.06 years	0.405	0.340	0.274	0.442	0.424	0.282	0.267
Samples for biomass study	Clay apricot buff	Shepherd gray Artie	Monierlife terracotta red	Shepherd blue Artie	MCA clay tile weathered green	Am roof coatings	MCA clay tile regency blue
Sample ID	931–933	677–678	549–551, 578	764–766	443–445	381–386	837–839
Sample area (m^2)	2.37E−02	1.58E−02	3.16E−02	2.37E−02	2.37E−02	4.74E−02	2.37E−02
SR initial	0.608	0.247	0.199	0.236	0.415	See below[a]	0.420
SR after 4.06 years	0.493	0.304	0.222	0.252	0.354		0.418

[a] Solar reflectance for Am Rooftile coatings exposed in Sacramento, CA.