Energy and Buildings 112 (2016) 184–197

Contents lists available at ScienceDirect

Energy and Buildings

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

Accelerated aging of treated aluminum for use as a cool colored material for facades

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ARTICLE INFO

Article history:
Received 6 July 2015
Received in revised form 3 December 2015
Accepted 9 December 2015
Available online 12 December 2015

Keywords:
Cool colored material
Electrolytically anodized aluminum
Highly reflective baked-on coating
Reflectance
Aging
Durability

ABSTRACT

Cool colored materials like membrane sheets and dried coatings exhibit higher reflectances in the near infrared region compared to conventional materials of the same color and are therefore desirable, as they provide energy economy and thermal comfort in cooling-dominated climates. They can also make reflective envelopes durable, owing to their lower surface temperatures. In this study, we experimentally show that different types of treated aluminum, like electrolytically anodized aluminum and aluminum with highly reflective baked-on coatings, can be employed as cool colored materials. Dark brown and light brown samples were examined in an accelerated aging test, and the optical properties and surface colors of the samples were compared with those of steels with reflective dried-on coatings. The treated aluminum samples exhibited stable optical properties and were durable. The accelerated aging tests, which involved exposure to ultraviolet radiation, heat, and water, were considered equivalent to actual long-term exposure, as evident from the decrease in gloss values of the samples. The aging conditions did not have a significant impact on the reflectances of the treated aluminum samples. Instead, our findings strongly suggest that the change in the reflectances of the tested samples may be due to accumulation of soil/dust and not due to surface aging.

1. Introduction

Increasing the solar reflectance of building envelopes can improve building performance by lowering the surface temperature, since a greater amount of solar radiation is reflected and more heat is emitted in the form of thermal radiation [1]. Reflective envelopes have three primary benefits: (1) reduction of the energy required for cooling, owing to a lowering of the surface temperature, (2) improvement in thermal comfort, owing to a suitable decrease in the heat gain, and (3) enhancement of durability, owing to a decrease in the degree of thermal movement and reduction of heat-related aging. In this regard, solar reflectance refers to the reflectance of direct and diffuse solar radiation in the 300–2500 nm range, which includes parts of ultraviolet, visible and near infrared radiation. The overall effects of these benefits depend primarily on the location of the building, climatic conditions, level of thermal insulation, and heat capacities of the envelope elements. However, one main drawback is the increase in the heating load demand during winter, when, e.g., the thermal performance of the building envelopes is not high enough. Higher reflective envelopes can be an energy solution when a larger reduction of annual cooling energy demand can compensate for the increased heating demand penalty. Previous studies have shown energy benefits where buildings with highly reflective facades can compensate increased heating demands with decreased an even larger decrease in cooling demands, and thus achieve annual energy demand reduction in cooling dominated regions [2,3]. Further, it has been indicated that reflective envelopes improve thermal comfort in various climates [4]. Buildings in cold climates may also represent a potential market for this technology, because these buildings are well insulated and the winters can be cloudy. In other words, the absorbance of the building envelope is not critical from an energy-saving viewpoint, but the durability of the facade should be high, given the low degree of thermal movement [5]. Buildings with reflective envelopes in cooling dominated regions can also expect durability improvements due to low thermal movement [5].

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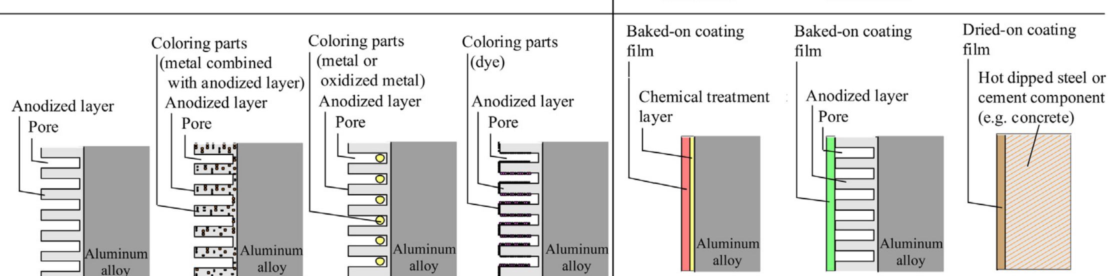
http://dx.doi.org/10.1016/j.enbuild.2015.12.014
0378-7788/

Cool colored materials, defined as materials having relatively high solar reflectance and high infrared emittance, can be a solution for reflective envelopes. Cool colored materials can reflect more near infrared radiation (NIR) than conventional materials, while exhibiting the same colors as those of conventional materials. Since their development over a decade ago, these materials have proven to be quite popular for use as roofing materials to prevent the heating of roofs due to strong solar radiation. As a result, these materials have been studied widely for use as roofing materials.

Previous studies have investigated painted cool colored roofs and cool colored materials consisting of integrating membranes [6–9]. When it comes to facades, designers are often more concerned about the esthetics (e.g., more color variation demands) than functionality. White facades are not always a satisfactory solution from an architectural design perspective. Dried-on coatings and tiles have also been investigated for use as cool colored materials for facades by measuring their optical properties, surface temperature, and surface heat transmittance [10–14]. There is a need to further study other types of cool colored materials. In this study, we focused on treated aluminum, i.e., aluminum with inorganic and organic film coatings, because of two reasons. To begin with, aluminum and anodized aluminum have a highly reflective surface. In the NIR range, the reflectances of aluminum and anodized aluminum are 0.85–0.97 and 0.6–0.8, respectively [15,16]. (The reflectance, however, depends on the thickness of the aluminum oxide layer.) These values are characteristic of cool colored materials. The high-NIR reflectance of aluminum is relevant after coating, only when the coating has selective transmittance and allows NIR radiation to pass through and be reflected back by the aluminum substrate.

The solar reflectance of cool colored materials changes in time because dust and soil are accumulated on the materials applied to the envelopes. It is therefore important to estimate the change in the solar reflectance. Moreover, since cool colored materials have only been developed recently, the long-term changes in their optical properties should be investigated thoroughly. The differences in the results obtained from accelerated aging tests and those from natural exposure tests should be studied, and a universal expression to predict the reflectance of aged materials should be developed [17–22]. Some previous studies have shown that the changes in the reflectance of roofing materials, such as membrane sheets, ceramic tiles, plated steels, and baked/dried coatings, are due to accumulation of soil and dust on their surfaces or due to surface aging [17–21]. Sleiman et al. developed a method to predict the solar reflectances of aged roofing materials in an accelerated manner. The tests were performed after 3 years of exposure to actual outdoor conditions in the United States, while taking into account soil and dust accumulation [23,24]. Their findings have led to the ASTM D7897-15 standard [25]. The changes in the solar reflectance due to soil and dust accumulation can therefore be estimated if the conditions (climates; material types) match those considered when deriving ASTM in previous studies [23,24]. Solar reflectance is also affected by the physical and chemical deterioration of cool colored materials, in addition to soil and dust accumulation. Before performing accelerated tests simulating outdoor exposure with ASTM D7897-15 to investigate the main factor in solar reflectance change

Table 1
Classification of various types of treated aluminum.

Type	Inorganic surface				Organic surface		
	A	B	C	D	E	F	G
Name	Treated aluminum						
	Clear anodized aluminum	Integral color-anodized aluminum	Electrolytically colored anodized aluminum	Dyed anodized aluminum	Organic coating system combined with chemical treatment	Organic coating system combined with anodized aluminum	Dried-on highly reflective coating systems (for comparison)
Section diagram							
Color variation	Bad	Good	Good	Good	Excellent	Excellent	Excellent
Durability	Very good	Very good	Very good	Not good	Very good [a]	Very good [a]	Very good [a]
Popularity	High	Medium	High	Low	High	High	High
Reflectance	High	Unknown	Unknown	Unknown	Unknown	Unknown	High
Focused type in this study	No	No	Yes	No	Yes	Yes	Yes

[a] Coatings using highly durable resin can significantly improve durability.