Solar Energy 149 (2017) 114–124

Contents lists available at ScienceDirect

Solar Energy

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

New strategy to mitigate urban heat island effect: Energy saving by combining high albedo and low thermal diffusivity in glass ceramic materials

E. Enríquez [a,*], V. Fuertes [b], M.J. Cabrera [a], J. Seores [a], D. Muñoz [a], J.F. Fernández [b]

[a] Centro tecnológico Vidres, S.L., Ctra. Onda, km 3.4, 12540 Villareal, Castellón, Spain
[b] Electroceramics Department, Instituto de Cerámica y Vidrio, CSIC, Kelsen 5, 28049 Madrid, Spain

ARTICLE INFO

Article history:
Received 13 January 2017
Received in revised form 4 April 2017
Accepted 5 April 2017

Keywords:
High albedo
Energy saving
Glass ceramic
Thermal diffusivity

ABSTRACT

The Global warming is a real problem that attracts great amount of investigations in order to reduce its adverse impact over the planet. The reduction of the heat island effect and the energy consumption into the building areas is an urgent goal. An interesting solution consists in the use of cool roofs, based on high reflective and high emissivity coatings. However, today, some cool roof materials possess some major drawbacks as high solar degradation, decrease of NIR reflection in comparison with the visible reflection and aesthetic restrictions. In order to overcome such limitations, in this work, a tile coated with a new glass ceramic material has been developed in order to improve the solar reflective properties and to reduce its thermal conductivity and increase the specific heat. These three parameters are key to obtain low thermal diffusivity materials to serve as efficient cool roof applications. The increase in solar reflectivity is complimented also by a high reflectivity in the NIR range that results highly convenient for colored materials. These combined properties in addition of increasing the albedo also contributed to improve the thermal comfort sensation inside the buildings. Therefore a great energy saving over 20% is determined in comparison with conventional ceramic tiles. In addition, these materials also offer a structural solution for durable facades and allow a great decorative variability.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

Nowadays, the Global warming is an urgent problem that attracts great amount of investigations in order to reduce its impact over the planet. The energy consumption in great cities contributes significantly to this effect, due to the creation of the urban heat island (UHI) and the CO_2 contamination (Chung et al., 2015; Cozza et al., 2015). Some solutions to reduce these phenomena are to increase green zones in the cities and to substitute hot pavements, such as asphalt or dark floor, for reflective materials. In addition, regarding to buildings sustainability, a priority challenge faces for solutions to reduce the energy consumption, both in winter and in summer. An interesting solution consists in the use of green roofs, which are composed of different kind of plants, such as grass, shrubs…and which heat absorption depends on the water evaporation and type of vegetation. The major associated problem is the maintenance issue. Another approach is the use of cool roofs, based on high reflective, that is, high albedo (reduction of solar radiation absorption), and high emissivity coatings, that contribute to decrease the ambient and inner temperatures. Some studies reveal that an increase of albedo by 25% and 15% in roofs and pavements, respectively, can reduce the radiative forcing by $0.15\ W/m^2$ over the global land area, which corresponds to a reduction of 44 Gt of emitted CO_2 (Santamouris, 2014). Therefore, moderated increase of the albedo produces great mitigation of heat island effects, which reduces the ambient temperatures. The mitigation efficiency has been proved to be higher in cool roofs than in green roofs.

Conventional roofs are made of asphaltic fabric, metal covering, rubber materials or typical clay tiles, which greatly increase the surface temperature and easily transfer heat to the inner of the building. Cool roofs are composed of a reflective covering, usually a white paint based on TiO_2 (also used as opacifier), aluminium trihydroxide (ATH) or organic compounds (Elton and Legrix, 2014; Ferrari et al., 2013; Karlessi et al., 2009; Kinoshita and Yoshida, 2016; Meyer et al., 2002). However, these kinds of materials are easily damaged due to the effect of soiling (Levinson et al., 2005) and the photodegradation of organic components under UV in TiO_2, which produces the white paint turns to yellowish. Therefore,

---

* Corresponding author.
E-mail address: esther@icv.csic.es (E. Enríquez).

http://dx.doi.org/10.1016/j.solener.2017.04.011
0038-092X/© 2017 Elsevier Ltd. All rights reserved.

the cool roof coating should be frequently restored. The cool paints base their high albedo on the high whiteness surfaces, which reflects almost the entire visible range of the solar spectrum. Additionally, these paints do not especially reflect the NIR radiation (having lower reflection than in the visible range) so the ambient temperature is thus transmitted. Recent works are focused on NIR reflection increase in order to achieve cool roofs with colored paints, with an alumina base, for example (Álvarez-Docio et al., 2017). However, good results are only achieved with light and pastel colors (Antonaia et al., 2016; Cozza et al., 2015; Zinzi, 2015).

Another solution for cool roofs consists of using ceramic tiles coated with reflective and NIR transparent coatings. These ceramic roofs have good technical characteristics such as mechanical properties, chemical inertia and fireproof, and the NIR radiation that penetrates into the transparent coating is reflected by the reflective coating (Ferrari et al., 2013; Levinson et al., 2007; Pisello et al., 2013). However, the coated tiles require at least three different layers and typically dissimilar materials. As consequence, a process with different sintering steps is required in these cases, which is not desirable for industry applications. Another tile solution consists of adding a thermal insulation layer below the glaze (Marangoni et al., 2016), typically by increasing the porosity that reduces the thermal conductivity but also reduces the mechanical properties. The introduction of an opacifier pigment (such as $ZrSiO_4$ and TiO_2) into the engobe layer also provides higher reflectance in the visible range due to their higher whiteness (Ferrari et al., 2013), however, these pigments increase considerably the tile cost.

The main use of cool materials is focused on roof coverings where the solar radiation has the highest incidence. Currently, these cool materials have also been proposed to be used in building facades since the new architectonic designs produce larger solar exposition (Ihara et al., 2015), which can further increase the impact of heat islands. For this purpose, ceramics are very effective materials because of its mechanical and chemical resistance, cleanliest, durability and decorative versatility.

Following the current state of the art, in this work, we propose an approach based on nanostructured glass ceramics that combines high albedo and low thermal diffusivity using the traditional single firing ceramics process. The unique characteristics of the nanostructured materials are based on greatly improving its reflectance, especially in the NIR range, reducing its thermal conductivity and increasing its specific heat (Hodgman et al., 1920). These three parameters are key to obtain a low thermal diffusivity material that is an essential factor to improve the heat island mitigation and also the thermal comfort sensation inside the buildings. Low thermal diffusivity may avoid the heat transmission both outward and inward, which provides great energy saving. The thermal diffusivity is related to the thermal conductivity and specific heat according to the Eq. (1).

$$\alpha = \frac{\kappa}{\rho C_p} \tag{1}$$

where α is the thermal diffusivity, κ is the thermal conductivity, ρ is the density and C_p the specific heat.

Moreover, the great mechanical, chemical and physical properties of the ceramic materials would allow their use in different building surfaces and would increase its lifetime, due to its resistance to the solar radiation and weather events. In addition, they provide surfaces with great stain resistance. The increase of the thermal inertia produced for the low thermal diffusivity, would reduce the heat transfer, preserving the inner temperature of buildings, which could also avoid the heat loss in winter, and therefore, it could produce larger energy saving and heat island mitigation.

2. Experimental procedure

2.1. Sample preparation

The glass ceramic material was prepared following the standard ceramic processing for the tile industry. Firstly, a frit previously melted at 1500 °C (previously warmed at 900 °C and then directly brought under the dwell temperature) and water quenched, was homogenized with kaolin in a weight proportion 90/10, in an alumina ball miller during 20 min with 37 wt% of water (Andrews, 1961; Reinosa et al., 2013, 2010). The frit composition expressed in term of equivalent oxides is shown in Table 1. Then, the material prepared was dried in powder to obtain a pressed pellet sample (pellets of ~10 mm in thickness, pressed at 39 MPa of pressure), or was deposited by the waterfall method (Norsker and Danisch, 1993) as a 300–900 μm in thickness coating on porcelain stoneware supports (SiO_2 65.60%, Al_2O_3 18.14%, Fe_2O_3 0.387%, TiO_2 0.428%, Na_2O 5.010%, K_2O 1.000%, CaO 0.472%, MgO 0.158%, P_2O_5 0.078% (Carbajal et al., 2007; Cavalcante et al., 2004)). Therefore, the layer structure of tiles consists in a porcelain support of 1 cm and the enamel coating. The particle size of this material after the milling and drying has a bimodal distribution with 12.95 μm and 225.33 μm. Finally, both pressed powder and compacted coating (tiles), for comparison purposed, were thermally treated in an industrial furnace at 1220 °C during 6 min with a 30 $°C\ min^{-1}$ heating rate. Additionally, colored tiles were processed by inkjet deposition of a saturated surface of black type ceramic nanopigment based on Fe-Cr-Mn oxide spinel, in order to check the validity of results in colored surfaces. This information is presented as supporting information.

The final composition of the glass ceramics expressed in term of equivalent oxides as SiO_2, CaO, ZrO_2, Al_2O_3, Na_2O, K_2O and ZnO is shown in Table 1. Table 1 also shows the composition of a conventional commercial matt glaze for comparison purposes, that hereafter it is denoted as glaze. This conventional glaze was chosen due to its similar feldspars composition, anorthite based, although with more glass phase.

The main parameters of the pressed powder samples and ceramic tiles prepared in this work are described in Table 2 (Table SI for colored ceramic tiles) that includes prepared samples and the commercial products. As explained, in order to be able to compare with raw TiO_2 and ATH powder (main commercial materials used as additives in reflective paints), samples were prepared as pressed powder in addition of as ceramic tiles (coating of porcelain substrates). In addition, a sample of reflective paint (Imperlux termic Outdoor, Arelux®) was prepared by depositing three layers (manufacturer recommendation to obtain high efficiency reflective effect) of paint on the same porcelain substrate.

The main physical parameters of reflective materials, TiO_2 (Feng et al., 2012; Jiménez-Pérez et al., 2015), ATH (Meyer et al., 2002; Shi et al., 2012; Wefers and Misra, 1987) and a standard reflective paint based on polyethylene composition, are provided for comparison purposed, Table 3.

2.2. Characterization

Microstructural characterization was studied by means of Field Emission Scanning Electron Microscopy (FESEM) using a Hitachi S-4700. Metalographically polished samples were chemically etched with 5 vol% of HF with the aim of removing the glass phase to reveal the microstructure. In addition, the crystalline phases formed were identified by using X ray diffraction (XRD) technique in a diffractometer Bruker D8 Advance with Cu Kα radiation, 40 kV and 40 mA, in sintered samples. The identification of the crystalline phases was realized by the comparison with the JCPDS patterns,

Download English Version:

https://daneshyari.com/en/article/5451073

Download Persian Version:

https://daneshyari.com/article/5451073

Daneshyari.com