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The application of nanosized silver colloids in far infrared low-emissive coating

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Abstract

In this study, far infrared low-emissive coatings have been prepared using a spin-coated 2-μm layer of commercial inorganic binder under a spin-coat produced from nanosized silver solution, resulting in Ag films of thicknesses between 0.1 and 1 μm. The bilayer coatings were baked at various temperatures for 30 min in air. The 1-μm Ag film baked at 150 °C exhibited an extremely low emissivity of 0.04 in the far infrared range wavelengths of 8 to 14 μm. In addition, this nano-silver paint showed good adhesive strength and the capability to withstand a neutral salt test.
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Keywords: Far infrared; Emissivity; Nanosized silver colloids

1. Introduction

Far infrared radiation is a part of the spectrum of radiation from the sun and is not visible to the eye. Despite having a long wavelength and relatively low energy, far infrared has been used for a range of applications. One such application is in the therapeutic field, usually commercialized in the form of a mat, sauna, blanket, clothing, etc. [1]. These products usually rely on some far infrared-radiating minerals or synthetic ceramics radiating 8 to 14 μm waves, the so-called atmospheric window, which also corresponds to human body's natural radiation. It is known that radiation in this wavelength range can penetrate human skin up to several centimeters to exert its influence. Far infrared is also utilized in spectroscopic analysis to investigate molecular interactions, such as in adsorption [2–4]. Thermal cameras with proper sensors [5], on the other hand, can detect radiation in the far infrared range and hence can be used for non-contact temperature measurement, quality control, inspection, etc. [6].

In general, the radiation emitted by a body depends on its temperature, chemical composition, microstructure and morphological features. The power emitted by a surface of a material is related to temperature to the fourth power. It is therefore a common technique to tailor the emissivity of a surface by applying a simple coating; for example, the use of porous ceramic coatings containing rare earth elements such as Er or Pr has been reported [7,8]. Metals, especially silver and aluminum, either in bulk or thin film form, show high spectral reflection and low thermal emissivity [9], properties that have been utilized to make various devices, such as optical filters [10], or coatings on architectural windows such as spectrally selective thin films for energy purposes [9].

In view of the fact that little information can be found in the literature on far infrared emissivity of coatings, the purpose of this study is to carry out systematic studies to investigate how emissivity changes with composition or structure of the coating. Specifically, nanosized silver colloids will be used as the functional material, due to their easy preparation and workability. Our final goal is to report on an efficient process that can be used to coat the substrate and achieve very low emissivity in the far infrared range of the spectrum.

2. Experimental details

2.1. Preparation of conventional paint composed of filler and binder

Various quantities of metallic fillers were mixed with an aqueous organic binder of acrylic resin (No. 1118-1, Eternal Chemical Co., Ltd., Taiwan) in a planetary mixer (KK-50,

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Table 1
Sources and specifications of metallic fillers used in this study

Filler	Particle size	Source
Al powder	10–20 μm	Showa, Japan
Ag powder	0.2–1.0 μm	Titanex Corp., Taiwan
Ag flake	0.5–5.0 μm	Titanex Corp., Taiwan
Nanosized silver colloids	28±10 nm	Synthesized in this lab

Mazerustar, Japan; using mixing program CH16) to obtain well-dispersed mixtures to use in emissivity tests. The sources and specifications of the metallic powders used are listed in Table 1. The nanosized silver colloids were chemically synthesized according to procedures previously reported [11]. Briefly, silver nitrate was reduced by formaldehyde in an alkaline environment, with polyvinyl pyrrolidone (PVP, MW=40,000; Acros Organic, USA) being used as the protecting agent. After separation and washing with acetone, these colloids were then re-dispersed in deionized water for further processing. According to measurements made in an earlier report, these colloids have an average size of 30 nm and about 5 wt.% residual PVP [12].

2.2. Film coating procedures

Alumina substrates (5 cm×5 cm, thickness 0.67–0.7 mm; Leatec Fine Ceramics Co. Ltd., Taiwan) were used in this study to test the changes in emissivity after the application of various coatings. For those conventional paints composed of filler and binder, the doctor blade (Braive, Belgium) method was employed to coat the substrate; film thickness was controlled at about 140 μm for these samples. After drying overnight at room temperature, the samples were then subjected to morphological observation using a scanning electron microscope (SEM; Model S-4700, Hitachi, Japan; operated at an accelerating voltage of 10 kV), surface roughness measurement using a scanning probe microscope (SPM; NS4, Multimode, Digital Instrument, Germany; whose controller is NanoScope IV, Veeco instruments, Santa Barbara, USA; operated in tapping mode with the tips of NSC15), and emissivity measurements.

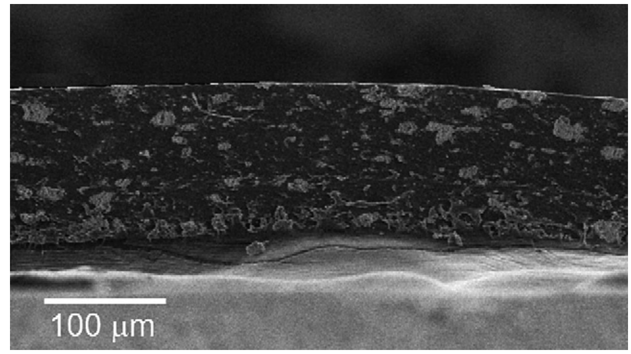

Fig. 2. Cross-section SEM image of a coating, which contains 40 wt.% microsized Ag powders in acrylic resin, deposited on an Al_2O_3 substrate.

As an alternative method, the alumina substrate was first coated with a layer of inorganic binder and then another layer of nanosized silver colloids using spin coating. The thickness could be adjusted by varying the rotation speed of the spinner (PM-490, Synrex, Taiwan). The inorganic binder chosen for this study was the SN-506 (Sino Technology Corp. Ltd., Taiwan), which is composed of nanosized silica and aluminous sol in aqueous solution (solid content ≥16.5%; specific gravity ~1.0) and could be heated to high temperatures. In addition to spin coating, the silver layer could also be applied using a simple spraying technique of the colloidal solution for easy workability. After coating with both layers, the samples were then dried at temperatures between 70 and 200 °C for 30 min before further tests.

2.3. Emissivity measurement

Two instruments were used to measure emissivity in this study. A forward-looking infrared meter (FLIR; ThermaCAM™ P65, FLIR Systems, Inc., USA) measured the average emissivity of a sample in the specific wavelength region of 8 to 14 μm, and a Fourier transform infrared (FTIR) spectroradiometer (Bomem MR104, ABB, Canada) measured the emissivity as a function of wavelength within the range of 0.7

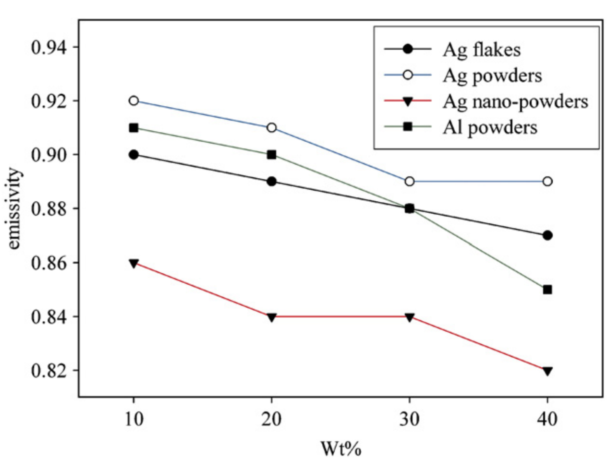

Fig. 1. Emissivity of conventional paints containing various metallic fillers at different concentrations (binder=acrylic resin).

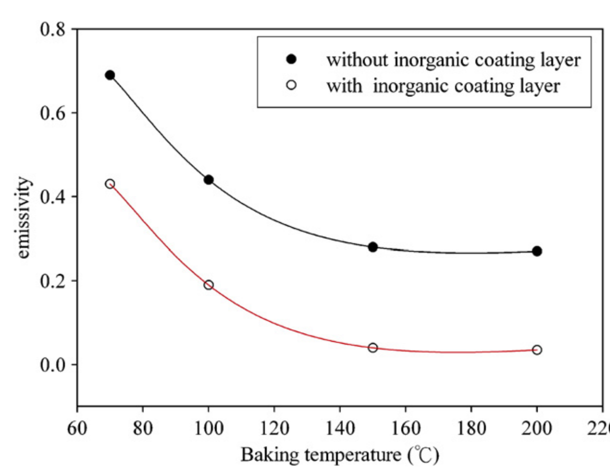

Fig. 3. Effect of the baking temperature on the emissivity of coatings with or without the inorganic resin underlying the silver film (thickness of silver film is about 1000 nm in this case).

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