

# Selective paint coatings for coloured solar absorbers: Polyurethane thickness insensitive spectrally selective (TISS) paints (Part II)

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## Abstract

Red, green and blue paints were prepared for use as thickness insensitive spectrally selective (TISS) paint coatings for solar façade absorbers. The paints were composed of a polyurethane resin binder in which various pigments were incorporated in such a way that they formed stable paint dispersions, satisfying stability criteria for façade coatings. A low emittance of the paints was achieved by using low-emittance aluminium flake pigments combined with iron oxide (red coloured paints). Black pigment was added to adjust solar absorptance. Blue and green paints were made by the addition of coloured aluminium flake pigment and the solar absorptance was also adjusted by the addition of black pigment. Efficiency for photo-thermal conversion of solar radiation was assessed by evaluation of the corresponding performance criteria, which enabled the selection of paints whose performance criteria values were higher than 0 (spectrally non-selective black coating). The results confirmed that blue and green paints and to minor extent red ones, combined selectivity with colour. The morphology of the paints was assessed, revealing that the colours originated from the deposition of finely dispersed colour and/or black pigment on the surface of the aluminium flakes during paint preparation.

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## 1. Introduction

Large areas of building façades are still a waiting use for photo-thermal conversion of solar radiation. However, the black colour of absorbers and sometimes the visibility of structural tubes and corrugations of metal sheets limit the architectural integration of solar collectors into a building façade. According to Weiss and Stadler [1], more than 85% of architects would prefer colours other than black, even if a lower efficiency would have to be accepted. For practical reasons and mainly to allow the use of unglazed coloured absorbers, the optical properties of the coatings should not be dependent on the paint thickness (thickness insensitive spectrally selective—TISS). TISS paints exhibiting spectral

selectivity and colours represent the main objective of this work.

In our laboratory we started to prepare TISS paint coatings in the framework of EU projects [2] but the TISS paints prepared were neither enough selective nor were their chroma values high [3]. Even the use of effect pigments (BASF, Paliogen, etc.) did not provide coatings whose spectral selectivity could compensate the loss of solar absorptance inherent in the smaller absorptance of coloured paints. The best selectivity achieved was still too low and the corresponding solar absorptance ( $a_s$ ) and thermal emittance ( $e_T$ ) values were  $\sim 0.83$  and  $0.55$ , respectively [4]. The examination of TISS paints revealed that the lateral size of the pigments used was too small preventing a thermal emittance lower than  $\sim 0.55$ . Accordingly, in the present study we focused on blue and green coloured aluminium flakes (CLE<sub>T</sub>) having a particle size of about  $\sim 50 \mu\text{m}$  (ECKART). In addition, red TISS paints

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made of pure (i.e. uncoated) aluminium flakes ( $LE_T$ ) and red iron oxide pigment were prepared and their properties compared with those of green and blue TISS paints made of coloured aluminium flake pigments [5,6].

Encouraged by the selectivity of coloured TISS paints based on silicone resin binder reported in Part I [7], we decided to make TISS paints where a polyurethane resin binder was used. Polyurethane paints are important for many applications because of their longevity in harsh environmental conditions. They are strong, tough and mechanically resistant and therefore such paints are without doubt suitable for unglazed solar absorber coatings. In addition, they are based on a two component resin system, which could be cured at ambient temperatures. Curing time could be shortened considerably after curing at 80 °C, a fact important for industrial fabrication of solar absorbers. Repainting is not a problem and could be done on-site for already installed collectors. Moreover, the polyurethane binder exhibits an excellent adhesion on various polymers suitable for the manufacturing of plastic absorbers. There is no plastic (polymer) material, which inherently exhibits optical properties such as spectral selectivity. The pigment loading in such a plastic would be too high leading to mechanical weakness of absorbers. Surface modification by applying TISS paints is the only way how to make plastic absorbers spectrally selective.

Accordingly, we believe that polyurethane-based TISS paint coatings, although in many respects similar to the silicone-based TISS paints reported in Ref. [7], deserve a separate study. An additional reason, which speaks in favour of a more detailed presentation of these paints lies in the fact that it is not a trivial problem to make coatings whose selectivity and colour is the same as those of TISS paint coatings made of silicone binder. In general, addition of the hardener increases the concentration of organic material and enhances the absorption and thermal emittance of the cured paint. Therefore, the problem of the high pigment loading in two component polyurethane resin system, a prerequisite to attain selectivity and colour, is addressed and evaluated from measurements of the solar absorptance and thermal emittance of these paints. Evidence that the use of coloured aluminium flake pigments for the preparation of blue and green coloured TISS paints is necessary, is also given. SEM micrographs of selected TISS paint coatings are reported to demonstrate the morphology of paints and the distribution of pigments in paints.

## 2. Experimental

### 2.1. Instrumental

The optical properties of paint coatings were determined from measurements of the IR reflectance spectra. Reflectance spectra in the visible (VIS) and near infrared (NIR) spectral regions were measured on Perkin Elmer Lambda 900 spectrometers equipped with integration sphere PELA

1020 between 2.5 and 0.25  $\mu\text{m}$  (University of Maribor). Reflectance spectra in the middle infrared spectral range (2.5–15  $\mu\text{m}$ ) were obtained with a Bruker IFS 66/S spectrometer equipped with an integrating sphere (OPTO-SOL) using a gold plate as a standard for diffuse reflectance.

Solar absorptance ( $a_s$ ) and thermal emittance ( $e_T$ ) values were determined from the measured reflectance spectra [8,9]. The solar absorptance  $a_s$  is theoretically defined as a weighted fraction between absorbed radiation and incoming solar radiation. It was calculated according to [8,9]

$$\alpha_s = \frac{\int_{0.3}^{2.5} S(\lambda)(1 - R(\lambda)) d\lambda}{\int_{0.3}^{2.5} S(\lambda) d\lambda}, \quad (1)$$

where  $\lambda$  is wavelength,  $R(\lambda)$  reflectance and  $S(\lambda)$  direct normal solar irradiance. It is defined according to ISO standard 9845-1 (1992) where an air mass is 1.5.

Thermal emittance  $e_T$  is a weighted fraction between emitted radiation and the Planck black body distribution  $r(\lambda, T)$  [8,9]:

$$e_T = \frac{\int_{2.5}^{15} r(\lambda, T)(1 - R(\lambda)) d\lambda}{\int_{2.5}^{15} r(\lambda, T) d\lambda}. \quad (2)$$

We calculated  $e_T$  values for 350 K, being close to operating temperature of solar collectors.

Performance criteria (PC) of paints were evaluated from the following relations:

$$PC_{0.34} = \alpha_s - 0.95 + 0.34(0.95 - e_T) \quad (\text{unglazed}), \quad (3)$$

$$PC_{0.50} = \alpha_s - 0.95 + 0.50(0.95 - e_T) \quad (\text{glazed}), \quad (4)$$

where the factors 0.34 and 0.50 refer to the case of unglazed and glazed façade absorbers [5,6]. For black spectrally non-selective paint ( $a_s = 0.95$ ,  $e_T = 0.95$ ) is  $PC = 0$ , while for highly selective sputtered coatings ( $a_s = 0.95$ ,  $e_T = 0.05$ ), the corresponding PC becomes 0.306 for unglazed and 0.45 for glazed absorbers. Any values between 0 and 0.306 could be expected for coloured spectrally selective paints.

Lightness ( $L^*$ ), colour coordinates ( $a^*$ ,  $b^*$ ) and chroma ( $C^*$ ) of coatings were obtained from the reflectance measurements performed on a Datascolor spectraflash SF 600 X (Color d.d.) instrument equipped with a standard programme for obtaining the corresponding CIELAB (CIE 1978) values [10].  $L^*$  represents the difference between light ( $L^* = 100$ ) and dark ( $L^* = 0$ ). The other two coordinates  $a^*$  and  $b^*$  represents the difference green ( $-a^*$ ) to red ( $+a^*$ ) and yellow ( $+b^*$ ) to blue ( $-b^*$ ). Using this system any colour corresponds to a place on the three-dimensional graph of  $a^*$ ,  $b^*$  and  $L^*$  coordinates. Chroma  $C^*$  is calculated according to [10]

$$C^* = \sqrt{(a^*)^2 + (b^*)^2} \quad (5)$$

as a distance from the origin  $a^* = b^* = 0$ . Chroma is the quality that distinguishes the colour from the grey shade. Namely, the origin  $a^* = b^* = 0$  is a chromatic and thus the

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