Thermal and optical behavior dataset of surfaces coated with high reflectance and common materials under different conditions, used in Brazil

Alvaro Caldeira e Rosa da Silva\textsuperscript{a,}\textsuperscript{*}, Claudinei Rezende Calado\textsuperscript{b}

\textsuperscript{a} Materials Engineering Department, Federal Technological Education Centre of Minas Gerais (Cefet/MG, Brazil)
\textsuperscript{b} Chemistry Department, Federal Technological Education Centre of Minas Gerais (Cefet/MG), Brazil

Article history:
Received 17 February 2020
Revised 6 March 2020
Accepted 11 March 2020
Available online 19 March 2020

Keywords:
Temperature data
Temperature profiles
Coatings thermal behavior
Surface reflectance index
Surface behavior
Infrared images
Heat flux behavior

Abstract
External and internal surface temperatures values of coated steel plates and the interior air temperature of a box-like model were collected throughout the time under different conditions: an artificial infrared radiation source was placed facing the external side of the plate to promote the temperature change, the energy power was variated by changing the distance from the plate and simultaneously different airflow conditions were inputted, data was collected by making experiments using the combination of distance and airflow changes. Reflectance raw data, of the materials, was also acquired by measuring the reflectance index of the samples according to ASTM E903 “Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres”. Amplified optical images and infrared images of the samples were taken (using a “Flir e4” infrared camera) while they were under the influence of the source in the three chosen distances (60 cm, 40 cm and 20 cm). Considering that researches at this particular field lack of more direct comparisons of temperature, reflectance and heat flux behaviours; between special high reflectance coatings and common ones when the substrate is steel, when the direction of airflow is changed and when the source is an infrared one; measurements intending to give faster insights and directions

\textsuperscript{*} Corresponding author.
E-mail address: alvaro.caldeira@gmail.com (A.C.e.R. da Silva).

https://doi.org/10.1016/j.dib.2020.105445
2352-3409/© 2020 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY license.
(http://creativecommons.org/licenses/by/4.0/)
Specifications Table

| Subject                                      | Materials Science - Surfaces, Coatings and Films. |
|---------------------------------------------|---------------------------------------------------|
| Specific subject area                       | Temperature, reflectance, optical and infrared imaging of coated surfaces. |
| Type of data                                 | Table                                             |
|                                              | Image                                             |
|                                              | Graph                                             |
|                                              | Figure                                            |

How data were acquired

Temperature data was collected using temperature sensors (type NTC 3950 100K thermistors), an Arduino microcontroller and software.

Reflectance index data was collected using a spectrophotometer (Perkin Elmer Lambda 1050 spectrophotometer, equipped with a 60 mm diameter integrating sphere) and according to ASTM E903 standard (Standard Test Method for Solar Absorbance, Reflectance, and Transmittance of Materials Using Integrating Spheres).

Amplified optical images were collected using a digital microscope.

Infrared images were collected using a Flir e4 infrared camera (all images were taken using the same emissivity setting: emissivity of 0.85 and “shooting distance” of 1 m).

Data format

Raw temperature (°C) - time (s) excel files.

Raw reflectance – wavelength (nm) text files.

Raw optical image files.

Raw infrared image files.

Organized excel temperature (°C) versus time (s) graphs.

Organized excel temperature (°C) versus combinations graphs.

Organized excel reflectance index versus wavelength (nm) files.

Analysed infrared images files.

Parameters for data collection

- For all temperature measurements: maximum temperatures values were considered when the sensors variations were less than 1 Celsius. The experiments were conducted in laboratory, the sensors fixing method and the energy source distance measurement method were the same for all experiments. The samples coating thickness were measured with a Check line, model 3000FX thickness gage and statistically analyzed to be sure that they had similar values.

- Samples for reflectance index measurements, were made using the same application method used for making the samples for temperatures measurements. Reflectance index was measured used a calibrated equipment and according to an international standard.

- All optical images of the samples were taken using a calibrated microscope and at a fixed distance.

- Infrared images were taken using a calibrated infrared camera at the same fixed distance. For the analysis of the infrared images the temperature scale was the same to favor comparisons.

Description of data collection

Temperature data was collected using temperature sensors (thermistors) and an Arduino Mega 2560 microcontroller connected via USB with a computer by Arduino IDE software.

The reflectance data was converted directly by the spectrophotometer in text files.

The optical and infrared images were converted directly by the equipment and transferred to a computer using a USB port.

(continued on next page)
1. Value of the data

• These data provide a way to compare common and high reflectance coatings under infrared energy and airstream variations, as there are no researches based on the behavior of common and high-reflectance coatings, that are subjected to those simultaneous variations.

• These compiled data provide, at one unique place, information about various properties (normally found in separated works): surface and air temperature values, visual surface aspects, surface radiation flux behavior and reflectivity values of the materials.

• These data provide a base to access the viability of using high reflectance coatings used in Brazil in the year of 2019, based on its temperature reduction potentials.

• These data can benefit researchers that work on the development of new or advanced coatings and materials. It is also suitable for those who need information about the way a material behaves under certain temperatures or conditions, the ones who need to learn fast about these types of material and for personal that seeks practical information.

• These data can be used as a way of comparing existing and development materials, streamlining future works in this field. These can also be used to compare and evaluate results of field tests on materials in use.

• These data facilitate and speed up the development of new researches, existing ones and promote a clear understanding of the modified behavior of coated surfaces.

2. Data description

This works contain data obtained from temperatures measurements made by thermistors, diffuse reflectance tests, infrared thermography, optical imaging and commercial prices.

The “raw temperatures data .xlsx” files, which are the imported values measured by the thermistors, obtained via the Arduino IDE software. E.g.: “Raw temperature data 20cm_no airflow_1” file are the data collected by the first experiment; when the radiation source was placed at 20 cm distance from the plates and no airflow was acting on the surfaces. This raw temperature data was filtered and organized; and the profile temperatures curves (Figs. 2–10), were made according to the sensor positions. This temperature profile curves and its tabulated data, are in another tab of the same raw file.

This raw temperature data was also organized into the propose combinations creating the graphs showed in Fig. 11.

The first graph in Fig. 11 has the temperatures for the grouped samples: e.g. the first three black colored bars are respectively the maximum temperatures for TC-01 sample for experiments made with no airflow; with lateral airflow and with frontal airflow.

The device that was built to measure the above-mentioned data can be seen at supplemental data 1.
Table 1
Description of the samples.

| No | Sample | Color   | Average coating Thickness (μm) | Sample description                          |
|----|--------|---------|--------------------------------|---------------------------------------------|
| 1  | TC-01  | Black   | 591.52                         | Common acrylic-based paint                  |
| 2  | TC-02  | White   | 649.32                         | Common acrylic-based paint                  |
| 3  | TSH-C1 | White   | 846.93                         | High reflectance composite paint            |
| 4  | TSH-C2 | White   | 812.17                         | High reflectance composite paint            |
| 5  | TSH-R1 | White   | 596.98                         | High reflectance composite paint            |

"Raw diffuse reflectance data .csv" files, which are the data obtained directly by the spectrophotometer. This data was exported to excel software and organized by the amount of energy reflected of each wavelength, creating “Diffuse reflectance versus wavelength graphs” file and the graph showed in Fig. 12. To make things clearer; the equipment emits one type of wavelength (ultraviolet, visible and infrared) at a defined interval of time and the amount of energy reflected by the surfaces is measured using the integrating sphere. E.g.: “Raw diffuse reflectance_TC-01” file has the reflectance test raw data for sample TC-01.

“Optical images .jpg” files have the twenty times amplified images of the surfaces of the samples. Imagens were taken from different points of the plates to show all the aspects observed. One image of each sample is shown in Fig. 13. Table 1 has a basic description and Fig. 1 has the pictures of the samples used to measure the temperatures and to collect the thermographic images, these were taken using a normal camera.

The “Raw infrared thermographic images .jpg” files are the thermographic images taken by the thermographic camera (supplemental data 6) of each material, considering only the source

![Fig. 1. - Description and pictures of the analyzed materials.](image-url)
Table 2
- Maximum external temperatures for the combinations: 60 cm/no airflow; 40 cm/no airflow and 20 cm/no airflow; measured using the infrared camera.

| Distance from the source (cm) | Emissivity (ε) | Maximum external temperatures (°C) |
|------------------------------|---------------|------------------------------------|
|                              | TC-01 | TC-02 | TSH-C1 | TSH-C2 | TSH-R1 |
| 60                            | 0.75  | 57.5  | 44.3  | 37.7  | 35.9  | 39.6  |
|                              | 0.80  | 55.7  | 42.1  | 36.6  | 35.0  | 38.7  |
|                              | 0.85  | 54.2  | 40.5  | 35.8  | 34.3  | 37.7  |
|                              | 0.90  | 52.5  | 39.9  | 35.0  | 34.5  | 37.1  |
|                              | 0.95  | 51.2  | 39.0  | 34.2  | 33.8  | 36.6  |
|                              | 0.99  | 50.3  | 38.6  | 34.7  | 33.3  | 36.0  |
| 40                            | 0.75  | 70.7  | 51.3  | 44.2  | 44.3  | 51.8  |
|                              | 0.80  | 68.4  | 49.0  | 42.8  | 42.1  | 49.9  |
|                              | 0.85  | 67.3  | 46.4  | 42.0  | 41.0  | 48.3  |
|                              | 0.90  | 64.4  | 45.4  | 40.9  | 39.8  | 48.0  |
|                              | 0.95  | 62.2  | 44.2  | 40.2  | 38.8  | 47.4  |
|                              | 0.99  | 60.6  | 43.4  | 39.4  | 39.0  | 47.1  |
| 20                            | 0.75  | 112.3 | 69.7  | 57.5  | 53.5  | 71.9  |
|                              | 0.80  | 106.4 | 67.3  | 52.6  | 54.1  | 69.2  |
|                              | 0.85  | 99.3  | 66.6  | 51.3  | 52.3  | 67.9  |
|                              | 0.90  | 97.8  | 64.0  | 50.5  | 49.2  | 65.6  |
|                              | 0.95  | 93.8  | 62.2  | 49.2  | 49.0  | 64.1  |
|                              | 0.99  | 95.5  | 59.2  | 50.3  | 49.1  | 63.1  |

Temperatures closest to the ones measured by the thermistors.

distance changes (no airflow was used in this test). The emissivity was changed, ranging from 0.75 to 0.90 for each distance. Then, these images were filtered and Figs. 15 to 17 were obtained using the own camera software (Flir tools).

These images were filtered to consider only a central region of the plates (to avoid errors generated by the edges and external influences). A fixed temperature scale was used to favor the comparisons. Table 2 has the maximum temperatures for each distance from the radiation source, obtained when the thermographic camera emissivity was changed.
The datasheet of the temperature sensors (thermistors) used to collect the temperature data and the datasheet of the microcontroller used for their electronic control can be seen respectively in “Supplemental data 2” and “supplemental data 3” if necessary.

To be easy to analyze this huge amount of data, tables were made, and can be consulted in “Supplemental data 4”, with the maximum average temperatures in Celsius and Kelvin for all combinations of “distance/airflow”.

A photo of the portable microscope and its technical specifications, used to generate the amplified optical images are available in “Supplemental data 5”.

“Supplemental data 6” has the infrared thermographic camera manual, for technical specifications consulting if needed.

“Supplemental data 7” has a table that contains the maximum temperature values for the three distances and for the changes on the emissivity of the infrared camera.

The yellow marked values are the ones closest to the temperatures measured by the sensors. Using this table, insights about the materials emissivity can be made, but having in mind that they are approximations and this property can only be well measured with the use of more advanced techniques that are not the scope of this work.

This file also has graphs, in Celsius and Kelvin, of the maximum temperatures when the radiation source is at the distance of 20 cm from the plates.

“Supplemental data 8” contains the tabulated data for Fig. 11 graphs. These data have the maximum temperatures for each sample and each distance from the source/airflow combination.

Table 3 has the price of the samples used in this work, considering the covering efficiency and an area of 1 m². This price was converted using the price of R$1,00 (Brazilian real) equal to US$4.14 (US dollar).

3. Experimental design, materials, and methods

Five samples and their descriptions (Fig. 1 and Table 1) formulated and supplied by an industrial collaborator were analyzed: two common commercial acrylic based paints and three with high reflectance pigments in its compositions.

These samples were applied (on the external side only) on ABNT 1020 steel plates, with dimensions of 0.3 m high, 0.3 length and 1.5 m thick. After drying completely, they were sanded, leaving the surface as smooth as possible and keeping the thickness of the samples as close to each other, to eliminate this variable influence on the results.

Common paints were applied using the air spray method, while high reflectance ones were applied using a brush, this was made on purpose to simulate different and common in-field methods.

To be able to collect temperature data from each type of material, a device (supplemental data 1) was built. This device consisted in a box-like structure made of plywood and externally isolated with Ethylene Vinyl Acetate (EVA). One of its side was removed to place the coated steel plates. In another similar structure, an uncoated ABNT 1020 steel plate was placed and the temperature values of this plate were measured in the same points and at the same time to be used as a reference.
Fig. 2. Temperature profiles of the coated samples. The graphs appear in the following order: 20 cm/no airflow.
Fig. 3. 20 cm/frontal airflow.
Fig. 4. 20 cm/lateral airflow.
Fig. 5. 40 cm/no airflow.
Fig. 6. 40 cm frontal airflow.
Fig. 7. 40 cm/lateral airflow.
Fig. 8. 60 cm/no airflow.
Fig. 9. 60 cm/frontal airflow.
Fig. 10. 60 cm/lateral airflow.
Fig. 11. - Temperature versus distance/airflow variations. * 1- External surface temperatures; 2- Internal surface temperatures; 3- Structure interior temperatures.
To collect data, thermistors (supplemental data 2), a Arduino Mega 2560 microcontroller (supplemental data 3) and the free version Arduino IDE software were used.

An artificial infrared radiation source promoted the temperature increasing. By varying the distance of this source from the plates (60, 40 and 20 cm), the amount of energy that hits these materials could be changed.

Also, the speed and directions of the air were modified. Three airflow configurations were chosen for the tests: no airflow acting, airflow with speed of 1 m/s hitting frontally the external surface of the plates and airflow with speed of 1 m/s hitting laterally the external surface of the plates. Using these configurations, we could see the influence of the convective heat coefficient in the temperatures.

Temperature measurements are a well-known technique used by many researchers: Hongbo, L., et al. (2014) [1], used sensors to measure temperature values of coatings under solar radiation, arranging the results in the form of graphs. Revel, G.M., et al. (2014) [2] used sensors to evaluate building envelope materials and Synnefa, A., Santamaouris, M., Livada, I. (2006) [3], studied reflective coatings on buildings for urban environment uses.

The experiments were conducted based on these “distance/airflow” combinations.

Each test had durations between one and a half hour and two hours, depending on the sample response to the energy input and its temperature variation during “heating” period. The procedure for each one of them was the following:

1 - The experiment began at room temperature.
2 - The radiation source (and the fan, when suitable) was turned on and temperature measurements were collected, until temperature variation was less than 1 °C (to promote temperature equalization).
3 - The radiation source was then turned off and data were collected until the period was completed.

Data were organized in two different ways: as temperature profile graphs (temperature versus time), (Figs. 2–10) according to the sensor’s locations, distances and airflows; to show how temperature behaves when the material is heated and cooled. And, as temperature versus combinations graphs (Fig. 11) to see the influence of air speed and directions changes. If the temperature values were shown in Kelvin, the temperature variations would be hard to see so, the graphs were made in Celsius degree to make these variations easier to see. The maximum average temperatures regarding all combinations are in the tables of supplemental data 4 file.

The figures show the temperatures profile only for one of the two or three experiments done for each combination.
Fig. 13. - Amplified optical images of the coated surfaces.
Room air curves, in each graph, refers to the ambient air and are the temperature values of the reference plate of only one of the tests performed, since observing the collected data it can be seen that the ambient temperature did not vary significantly for the same set of samples tested.

Reflectance tests are made mainly to evaluate the isolation potential of materials used to build a structure or building, the more a material reflects a type of radiation the lower is its temperature on the other side. Experiments done by Rossi, F., et al. (2016) [4] with retro-reflective materials and by Coser, E., Moritz, V.F., Krenzinger, A., Ferreira, C.A. (2015) [5] with paints with infrared reflective properties, shows the use of this technique. Some other authors: Uemoto, K.L., Sato, N.M.N., John, V.M. (2010) [6] and Synnefa, A., Santamouris, M., Akbari, H. (2007) [7], have used temperatures measurements along with reflectance test to make assessments about its efficiency.

The diffuse reflectance data was collect using a Perkin Elmer Lambda 1050 spectrophotometer, equipped with a 60 mm diameter integrating sphere and according to ASTM E903 standard (Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres). These raw data were organized, and a graph of reflectance versus wavelength of the samples was created (Fig. 12).

The amplified (twenty times) optical images (Fig. 13) of the coated and uncoated external surfaces, were collected using a portable digital microscope (with technical specifications describe at “supplemental data 5”) at a fixed distance from the surfaces. Those images were taken at different points of the plate to show all their aspects.

Infrared thermographic tests are used to evaluate the thermal behavior of a surface, its heat flux, to collect surface temperature values and to see possible defects. Calado, C.R., et al. [8] used it to detect manufacturing internal defects in ceramic tiles.

The thermographic images were collected using a Flir e4 infrared camera (Supplemental data 6) and all images were taken using the emissivity of 0.85 and at "shooting distance" of 1 m.

Filtered thermographic images (Figs. 14, 15 and 16) consist of the infrared images that shows the temperatures values and also the heat flux behavior at the surface. The central area of the plates was highlighted to eliminate the possible influence of the edges and a fixed scale for each
distance was used to favor the comparisons. No airflow was acting when these measurements were made.

All thermographic images were filtered using the same temperature scale to favor comparisons. Table 2 shows the maximum external temperatures found in Celsius, for the three distances and for changes on the emissivity of the infrared camera. Supplemental data 7 shows the maximum temperatures in the absolute scale (Kelvin), when the camera emissivity was changed and the graph of the maximum temperatures of each sample when the radiation source is at 20 cm from the plate surface.
Finally, the average cost of the common and high reflectance coatings used at this work, similar to the ones found in the market of Brazil, is showed in Table 3. Most of the time, researchers do not have access to the composition of the material used due to patent issues. So, the use of experimental thermal behavior along with the coating cost or price can be an alternative to access the viability of a particular material.

Acknowledgments

Federal Technological Education center of Minas Gerais (Cefet-MG).

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi: 10.1016/j.dib.2020.105445.

References

[1] L. Hongbo, C. Zhihua, C. Bindin, X. Xiao, W. Xiaodun, Studies on the temperature distribution of steel plates with different paints under solar radiation, Appl. Therm. Eng. 71 (2014) 342–354, doi: 10.1016/j.applthermaleng.2014.06.031.
[2] G.M. Revel, Cool products for building envelope - part II: experimental and numerical evaluation of thermal performances, Sol. Energy 105 (2014) 780–791, doi: 10.1016/j.solener.2014.02.035.
[3] A. Synnefa, M. Santamaouris, I. Livada, A study of the thermal performance of reflective coatings for the urban environment, Sol. Energy 80 (2006) 968–981, doi: 10.1016/j.solener.2005.08.005.
[4] F. Rossi, Experimental evaluation of urban heat island mitigation potential of retro-reflective pavement in urban canyons, Energy Build. 126 (2016) 340–352, doi: 10.1016/j.enbuild.2016.05.036.
[5] E. Coser, V.F. Moritz, A. Krenzinger, C.A. Ferreira, Development of paints with infrared radiation reflective properties, Polymers (Basel) 25 (2015) 305–310, doi: 10.1590/0104-1428.1869.
[6] K.L. Uemoto, N.M.N. Sato, V.M. John, Estimating thermal performance of cool colored paints, Energy Build. 42 (1) (2010) 17–22, doi: 10.1016/j.enbuild.2009.07.026.
[7] A. Synnefa, M. Santamouris, H. Akbari, Estimating the effect of using cool coatings on energy loads and thermal comfort in residential buildings in various climatic conditions, Energy Build. 39 (2007) 1167–1174, doi: 10.1016/j.enbuild.2007.01.004.
[8] C.R. Calado, Porosity and delamination defect detection in ceramic materials by active infrared thermography and optical digital microscopy, Mater. Sci. Forum 798–799 (2014) (2014) 671–676, doi: 10.4028/www.scientific.net/MSF.798-799.671.