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Research Article

Emissivity Measurement of Semitransparent Textiles

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In the textiles production industry it is more and more common to advertise new textiles, especially for sportswear, by claiming their ability to emit IR radiation in the long wave band at a higher degree with respect to normal clothes, that is highly beneficial to improve sporting performances. Three textiles are compared, one normal and two "special," with Ag^+ ions and carbon powder added, with different colors. The emissivity of the textiles has been measured to determine if it is increased in the "special" textiles with respect to the normal one. No substantial increase has been noticed. Nonetheless, the test implied some nonstandard procedures due to the semitransparent nature of the textiles, in comparison with the normal procedure that is commonly used on opaque surfaces.

1. Introduction

Two textiles are made of polypropylene (PP) and charged with Ag^+ ions and Carbon powder. They differ from the color that is green for the first and blue for the second. They are compared with a third "normal" PP textile of green color and the same weft of the previous. The purpose is to demonstrate if the emissivity in the Infrared-Long Wave band (IR-LW) [1–3] of the charged textiles is increased or not due to the presence of the charging elements.

The measurement is carried out in the wavelength interval 8–14 μm; it is an integral measurement; that is, it represents the average value of the spectral emissivity in the considered interval [4].

The measurement is carried out by means of a microbolometric camera that exhibits an almost flat spectral response at the various wavelengths. Therefore, it is not taken into account any spectral response of the detector even because of the comparative nature of the measurement [5, 6].

Any evaluation of the taking angle is neglected and so the dependence of the emissivity with the view angle. The measurement is performed with a normal view with respect to the textiles [7].

The measurement technique consists in laying down the charged textiles, to be measured, and the "normal" (the reference) one, side by side and in contact with a thick aluminum plate that is assumed to be as much isothermal as possible. Observing the two textiles (that own the same temperature) by an IR camera allows to evaluate the IR radiation emitted by their surfaces. The possible difference in the radiation collected by the IR camera in correspondence of the "measured" textiles and the "reference" one is due to the emissivity difference. In this case the measurement is more difficult than the one for an opaque surface in so far the textiles are semitransparent and the radiation collected by the camera is due to the contribution of the textiles themselves plus the background, each one emitted with its own emissivity and weighted by the surface fraction that it covers. Therefore, a preliminary assessment of the transmittance coefficient of the textiles is done in such a way to determine the percentage of radiation emitted by the textiles themselves and the percentage that they transmit, coming from the background.

2. Equations Related to the Emissivity Measurement

In case of an opaque object at temperature T_o and emissivity ε_m and with a surrounding environment at temperature T_a the radiance measured by the IR camera is given by [8]

$$I_m = \varepsilon_m I_o + (1 - \varepsilon_m) I_a, \tag{1}$$

where $\varepsilon_m I_o$ is the radiance emitted by the object surface and $(1-\varepsilon_m)I_a$ is the radiance generated by the environment and reflected by the object surface. In (1) the effect of the absorption and emission of radiation by the atmosphere is neglected due to the small distance between the camera and the object. In case of comparative measurement, in which one material is the reference (subscript r) and the other is the measured one (subscript m) the ratio between the two emissivities is given by

$$R = \frac{\varepsilon_m}{\varepsilon_r} = \frac{I_m - I_a}{I_r - I_a}, \tag{2}$$

where I_r, I_m, and I_a are the radiances measured by the camera in correspondence of the reference material, the measured material, and the environment, respectively.

In case of semitransparent material, as it is the case of the textiles, (1) is transformed in

$$I_m = (1-\tau_m)[\varepsilon_m I_o + (1-\varepsilon_m)I_a] + \tau_m I_s, \tag{3}$$

where τ_m is the transmittance coefficient of the textiles (that is the one's complement of the surface percentage covered by the textiles) and I_s is the radiance emitted by the surface of the metallic plate on which the textiles are laid down and that is heated at a constant temperature during the measurement. In case of the comparative measurement of semitransparent materials with transmittance coefficients τ_m and τ_r, respectively, for the measured and reference textiles, one obtains

$$R_{st} = \frac{\varepsilon_m}{\varepsilon_r} = \frac{1-\tau_r}{1-\tau_m}\frac{I_m - I_a - \tau_m(I_s - I_a)}{I_r - I_a - \tau_r(I_s - I_a)}. \tag{4}$$

3. Measurement Uncertainty Analysis

The evaluation of the ratio R_{st} by means of (4) requires the measurement of six quantities. Each one is measured many times (some tenths for transmittances to some thousands for radiances). The statistical evaluation of (4) is therefore necessary, together with its uncertainty by means of the uncertainties propagation:

$$\delta R_{st} = \sqrt{\begin{array}{l}\left[\dfrac{\partial R_{st}}{\partial \tau_r}\delta\tau_r\right]^2 + \left[\dfrac{\partial R_{st}}{\partial \tau_m}\delta\tau_m\right]^2 + \left[\dfrac{\partial R_{st}}{\partial I_r}\delta I_r\right]^2 \cdots \\ \cdots \left[\dfrac{\partial R_{st}}{\partial I_m}\delta I_m\right]^2 + \left[\dfrac{\partial R_{st}}{\partial I_a}\delta I_a\right]^2 + \left[\dfrac{\partial R_{st}}{\partial I_s}\delta I_s\right]^2\end{array}}, \tag{5}$$

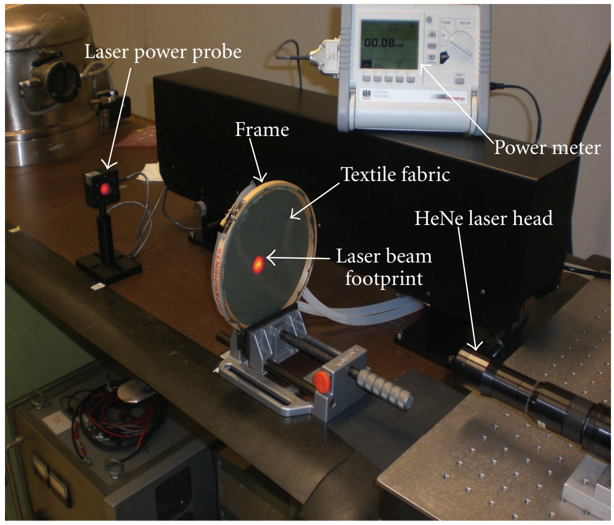


Figure 1: Experimental layout for the transmittance measurement in the optical wavelength range.

where the uncertainties $\delta\tau_r, \delta\tau_s, \ldots, \delta I_s$ have been estimated by their standard deviation and the partial derivatives of R_{st} are given by

$$\begin{aligned}
\frac{\partial R_{st}}{\partial \tau_r} &= R_{st}\left[\frac{I_s - I_a}{I_r - (1-\tau_r)I_a - \tau_r I_s} - \frac{1}{1-\tau_r}\right], \\
\frac{\partial R_{st}}{\partial \tau_m} &= R_{st}\left[\frac{1}{1-\tau_m} - \frac{I_s - I_a}{I_m - (1-\tau_m)I_a - \tau_m I_s}\right], \\
\frac{\partial R_{st}}{\partial I_r} &= R_{st}\frac{-1}{I_r - (1-\tau_r)I_a - \tau_r I_s}, \\
\frac{\partial R_{st}}{\partial I_m} &= R_{st}\frac{1}{I_m - (1-\tau_m)I_a - \tau_m I_s}, \\
\frac{\partial R_{st}}{\partial I_a} &= R_{st}\left[\begin{array}{l}\dfrac{1-\tau_r}{I_r - (1-\tau_r)I_a - \tau_r I_s} - \cdots \\ \cdots \dfrac{1-\tau_m}{I_m - (1-\tau_m)I_a - \tau_m I_s}\end{array}\right], \\
\frac{\partial R_{st}}{\partial I_s} &= R_{st}\left[\begin{array}{l}\dfrac{\tau_r}{I_r - (1-\tau_r)I_a - \tau_r I_s} - \cdots \\ \cdots \dfrac{\tau_m}{I_m - (1-\tau_m)I_a - \tau_m I_s}\end{array}\right].
\end{aligned} \tag{6}$$

4. Experimental Apparatus for Transmittance Measurement

The measurement apparatus for the transmittance evaluation consists of a Continuous Wave HeNe laser with emission at the wavelength $\lambda = 632.8$ nm, at a power of 10 mW. The beam is expanded to an FWHM of almost 2 cm. The power of the beam is measured by a suitable detector connected to a power meter, once without any obstacle in the optical path and then with the textiles in between. From the ratio of the measured power with and without the textiles, the transmittance is obtained. See Figure 1.

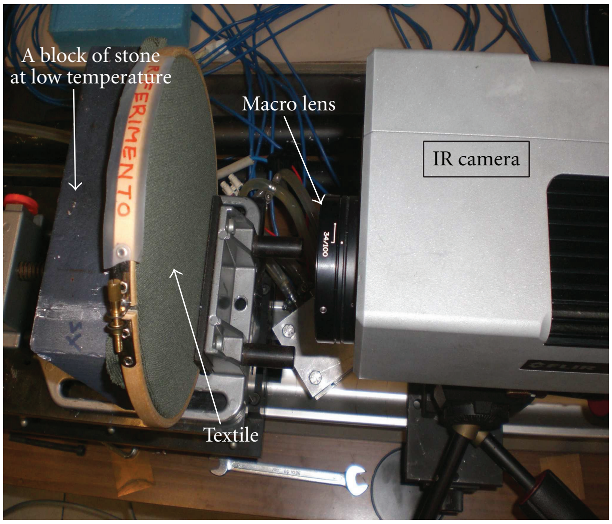


FIGURE 2: Experimental layout for the transmittance measurement in IR wavelength range.

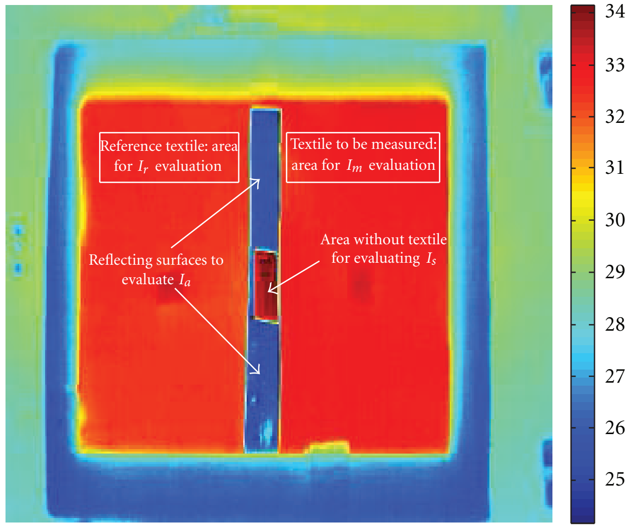


FIGURE 4: IR image relative to Figure 3. See the indication of the areas utilized to evaluate (4).

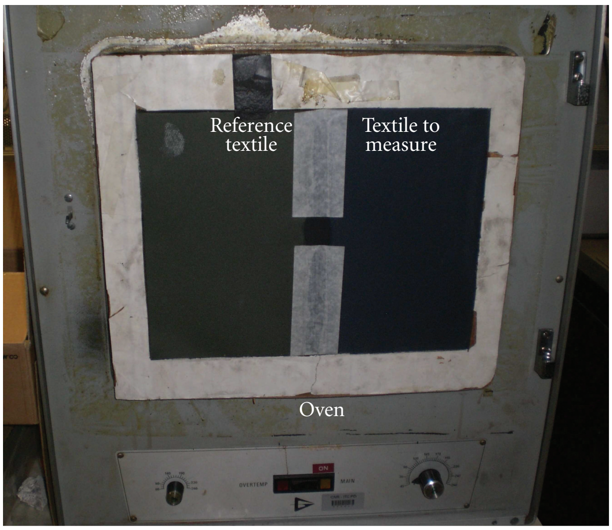


FIGURE 3: Experimental layout for the emissivity measurement.

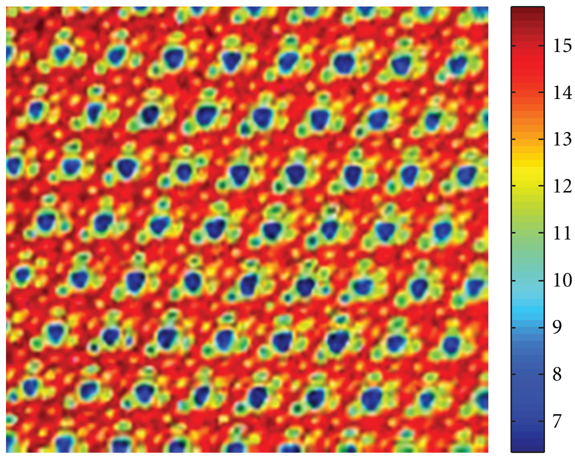


FIGURE 5: Results of the transmittance measurement in the IR. Notice the regular appearance of the cold background areas.

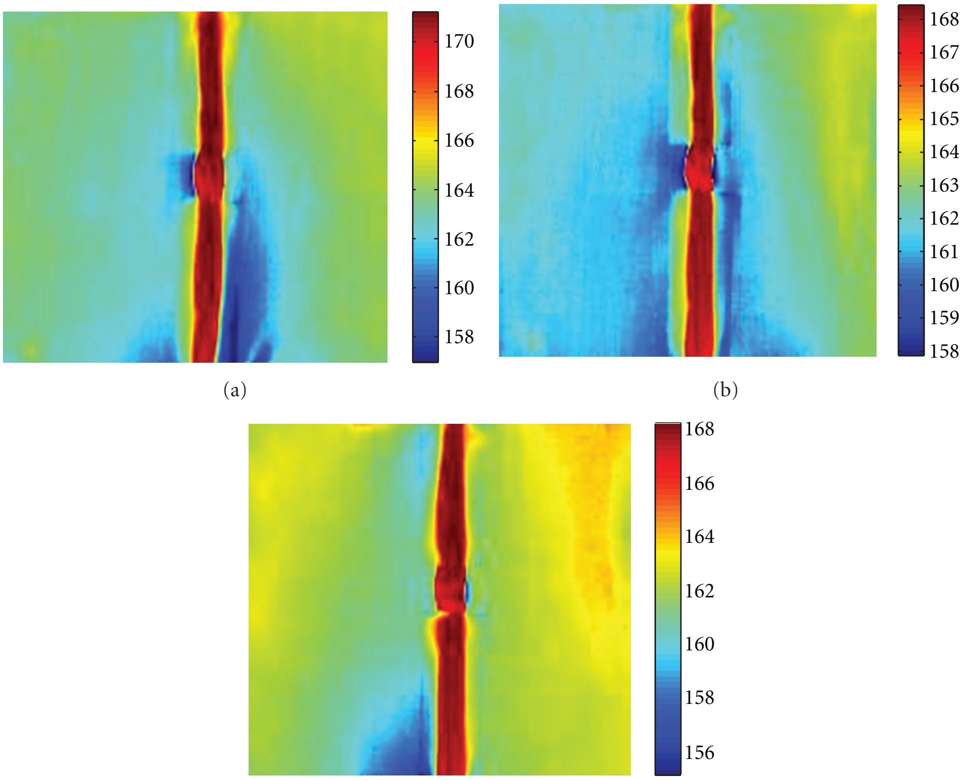
TABLE 1: Results of the transmittance measurement by laser attenuation.

Textiles	Transmittance Mean ± standard dev.
RV	0.13 ± 0.02
CV	0.14 ± 0.02
CB	0.15 ± 0.02

A possible objection to the assessment of the transmittance as described above is connected to the wavelength of the laser source that is 20 times smaller of the radiation considered in the emissivity evaluation. On purpose a second experimental layout has been prepared. An IR camera with a macro lens (~100 μm/pixel) observes a cold background through the textiles at ambient temperature. The background object has no contact with the textiles, avoiding any conduction effect. See Figure 2.

5. Experimental Apparatus for Emissivity Measurement

The measurement apparatus is composed of an aluminum plate 2 cm thick, on which the reference and measured textiles are laid down side by side. The plate is successively inserted on the opening of an oven from which it receives heat. The aluminum plate guarantees the uniformity of the temperature of the textiles. An IR camera observes the textiles that are heated at a temperature of 35-36°C, around the human body temperature. See Figure 3.



(a) (b) (c)

Figure 6: (a) Textiles RV on left and CV on right; (b) textiles RV on left and CB on right; (c) textiles CV on left and CB on right.

In the successive Figure 4 the IR image relative to Figure 3 is shown. The areas utilized for the radiance measurements, according to (4) are indicated.

6. Measurements of Transmittance by Laser

The measurements have been carried out on three textiles: the reference one of green color RV, the charged one of green color CV, and the charged one of blue color CB. Each textile has been positioned at 1/4, 1/2, and 3/4 of the laser beam optical path between the laser head and the detector. For each position the measurement has been repeated four times, for a total of 12 measurements. The results with mean values and standard deviations are reported in Table 1.

A second transmittance measurement has been carried out in the IR. Figure 5 shows the IR image of the textiles with some cold areas regularly disposed in the image. The measurement in this case consists in determining the percentage of cold areas in comparison with the total area. The weakness of this technique is related to the arbitrary threshold that should discriminate between cold and hot areas. By varying the threshold between 10.0 and 11.0°C one obtains a transmittance value between 0.116 and 0.170. By choosing a threshold at 10.5°C one obtain a transmittance of 0.142 close to the values obtained with the laser attenuation technique.

Table 2: Results of the emissivity ratio according to (4).

Textiles	R_{st} Mean ± standard dev.
RV-CV	1.036 ± 0.065
RV-CB	1.061 ± 0.053
CV-CB	1.059 ± 0.065

7. Emissivity Measurement

Three experiments have been carried out:

(i) in the first, the reference textile RV is on the left and the charged green textile CV is on the right, see Figure 6(a);

(ii) in the second, RV is on the left while the charged textile of blue color is on the right, see Figure 6(b);

(iii) in the third, two charged textiles are directly compared: CV on the left and CB on the right, see Figure 6(c).

The IR images and the computations are done in Object Signal, units furnished directly by the IR camera software, before the transformation in temperature unit, and proportional to radiance.

In Table 2 the results are reported.

8. Conclusion

The CV textile shows an emissivity 3.6% higher than the RV. The CB textile presents an emissivity 5.3% higher than RV. The measurements are affected by an uncertainty of about 5%, that means the differences in emissivity are comparable to the measurement error. The last test, that directly compares the two charged textiles, shows that the blue textile has an emissivity higher than the green one. From these considerations one could guess that the colors used in the textiles affect emissivity more than the charging elements.

Acknowledgment

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