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Radiative properties of firefighters' protective clothing worn during forest fire operations

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Abstract

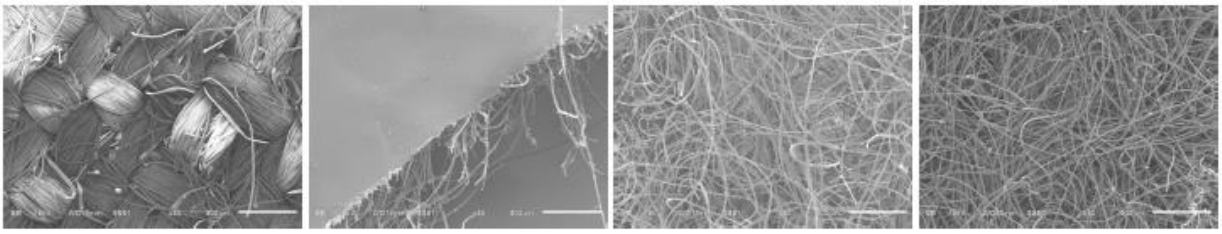
The present work addresses the spectral radiative characterization of firefighters' jackets, which are the main component of their Personal Protective Equipments (PPE). During their tasks firefighters have to wear their PPE that must ensure simultaneously comfort, mobility and first and foremost thermal protection. Over time the nature and constituents of the firefighter's coats have strongly evolved. They were made up with leather for a long time, and are mainly designed in multiple-layer fabrics today. Given that, we can find many garments which overcome with one or several specifications in terms of comfort, thermal protection, heat dissipation, moisture barrier, mobility, weight … Numerous studies are found in the literature dedicated to one of these properties. None of the works related to their thermal performance considers the spectral radiative properties, however. Obviously, thermal protection is of primary importance and since firemen may be exposed to various heat threats, which present different spectral characteristics, it becomes also of prime interest to investigate the spectral radiative properties of these new products. To our best knowledge, the last study which referred to the spectral properties dates back to 1974 with the work by Quintiere [1] who provided the spectral radiative properties of several fabrics, within a relatively wide spectral range from 0.3 to 22 µm. The present study aims at investigating the spectral radiative properties of currently available fabrics used by French firefighters in the range from 0.25 to 16 µm covering both IR-Visible range.

Keywords: *Fire protective clothing, radiative properties, absorptivity*

1. **Introduction**

A standard fire intervention jacket (fig 1 (a)) is made of four layers (fig 1 (b)): a fire resistant outer layer in aramid (fig 2 (a)), a moisture barrier layer (fig 2 (b)) and a double inner layer for thermal barrier and comfort (fig 2 (c) and (d)). Our study is focused on the measurements of radiative properties of five fire intervention jackets provided by the Rescue Service Department of Meurthe et Moselle and of Vendée, France. Jacket #1 and #2 are blue, #3 is orange and #4 is gold. The fifth fire jacket is made of leather and is no more used in fire intervention in France since 2002.

Figure 1. Standard fire protective jacket (a). Samples of the different layers involved (b)



(a) (b) (c) (d)

Figure 2. The different layers of the jacket zoomed 50x (a) Outermost layer (b) Moisture barrier (c) Innermost layer #1 (d) Innermost layer #2

The experimental set-up used for the radiative property measurement was described in a previous study [2]. The radiative properties measured are the directional-hemispherical transmissivity τ_ν and directional-hemispherical reflectivity ρ_ν. These properties depend on the wavelength. Then, the spectral absorptivity α_ν is deduced from the radiative balance,

$$\rho_\upsilon + \tau_\upsilon + \alpha_\upsilon = 1$$

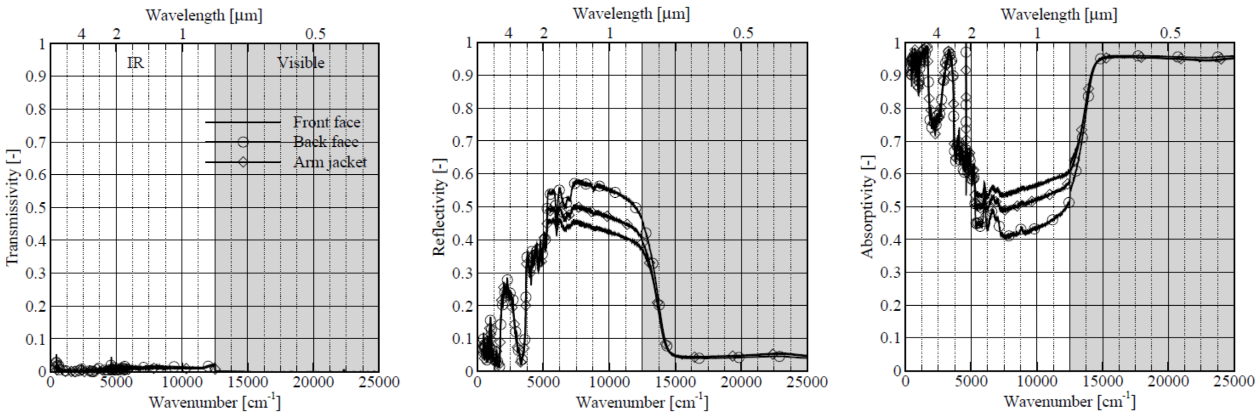
Directional-hemispherical transmissivity and reflectivity measurements were carried out in the visible-infrared range from 450 cm^{-1} to 25000 cm^{-1}. An FTIR spectrometer (Vertex 80 Bruker), an IR integrating sphere by Labsphere and an MCT detector by InfraRed Associates were used for the radiative properties in the IR range. In the visible range, a sphere from Labsphere and a spectrophotometer Cary 500 of Varian were used.

In the present study the homogeneity of the radiative properties was tested first. Then, a specific evaluation was conducted on the individual radiative properties of each layer of the fire intervention jacket #1. Finally, the effect of the fabric color and of the dyeing mode was evaluated, comparing the results for the different fire jackets.

2. Results

2.1. Repeatability test

Radiative properties may depend on the localization of the sample on the fire jacket. Three samples were selected from the jacket: on the front face, on the back face and on the jacket arm. The directional-hemispherical transmissivity, the directional-hemispherical reflectivity and the absorptivity for one fire jacket are presented in Figure 3, allowing to check for the homogeneity of the radiative properties on the jacket.

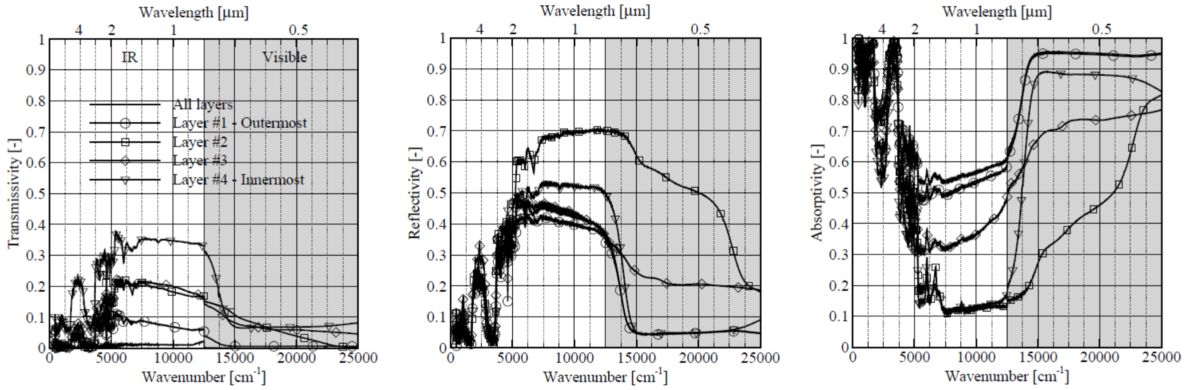


(a) Transmissivity (b) Reflectivity (c) Absorptivity

Figure 3. Radiative properties of three samples selected on the same fire jacket #1

Results reveal that the properties are quite similar for the three samples and that the radiative properties of the fire jacket are near homogeneous. It can be observed that the spectral transmissivity is quasi-null, whereas the spectral reflectivity can reach up to 55%. The average absorptivities over the whole spectral range are estimated to 80%. Consequently, no direct radiative transfer will occur through the jacket considering the zero transmission, but the high absorptivity will result in heat absorption which will be partly transferred from layer to layer through the jacket.

2.2. **Radiative properties of the different layers**

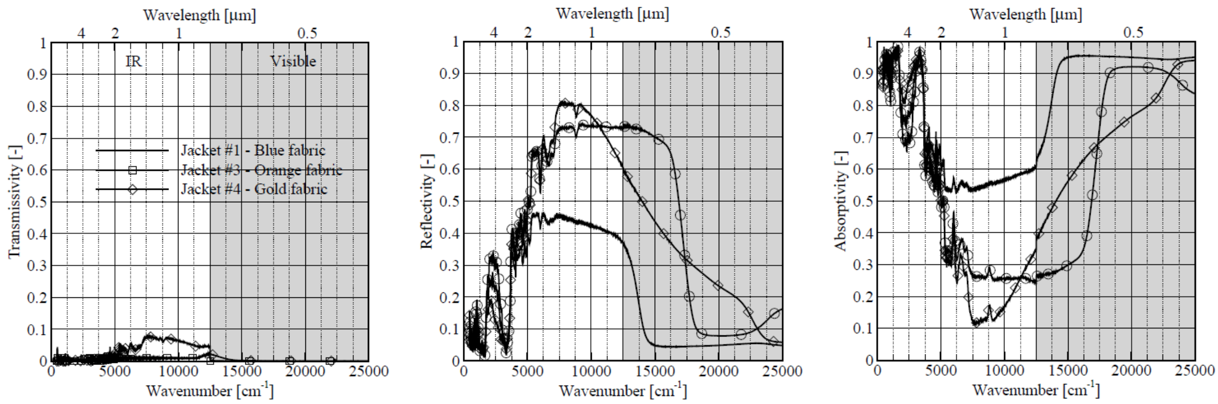


(a) Transmissivity *(b) Reflectivity* *(c) Absorptivity*

Figure 4. Radiative properties of different layers of the fire intervention jacket #1

The jacket #1 is made up with the 4 layers presented previously. Their respective radiative properties are presented in Figure 4 and compared with the complete jacket properties. The first observation is that each layer has a non zero transmissivity, but their product involved in the complete jacket finally results in a transmissivity equal to zero (fig 4 (a)). Note that the transmissivity of the outermost layer is too weak to allow significant multiple reflections inside the jacket. The reflectivity of the fire jacket is mainly due to the outermost layer (the curves of the reflectivity for this layer and the one of the complete jacket are superimposed in figure 4(b)). Strong variations of the absorptivity are observed as a function of the wavenumber (fig 4 (c)). The absorptivity is significantly lower for the inner layers, which results in a global behavior mainly influenced by the outermost layer, in particular in the infrared range. Globally, the radiative heat transfer through the fire intervention jacket is mainly controlled by the outermost layer.

2.3. **Effect of the fabric color**



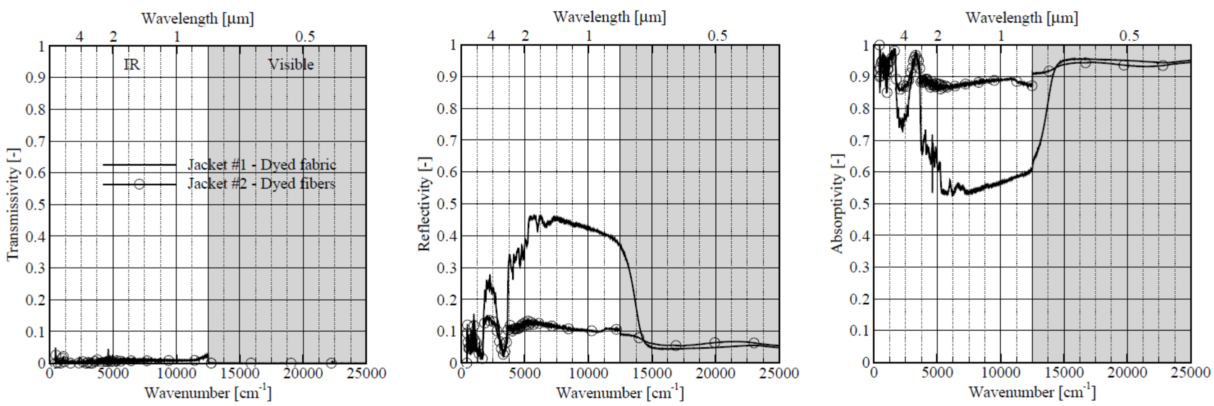
(a) Transmissivity *(b) Reflectivity* *(c) Absorptivity*

Figure 5. Comparison of radiative properties of different sample for a same fire jacket

Three different jackets (jacket #1, jacket #3 and jacket #4) with different colors (blue, orange and gold, respectively) have been tested in order to evaluate the impact of the fabric color.
Transmissivity values are still very low (fig 5 (a)) close to zero, except for jacket #4 for which values up to 9 % are obtained. The effect may due to the weaving mode which produces some little gaps between the polymer fibers, making the surface porous. The reflectivity is larger for the orange and gold jackets than for the blue one (fig 5(b)). Consequently, the spectral absorptivities of the orange and gold jackets are weaker than the one of Jacket #1(fig 5(c)). However, these discrepancies are mainly observed in the near IR and in the visible domain. They are very weak in the middle IR range, which results in close average values for all the jackets, since presented average values correspond to Planck's averaging performed for radiative sources with temperature in the range between 800 and 1400 K. A maximum absorptivity of 80% is finally found for the gold jacket, while a minimum value of 75% is obtained for the orange one. As a summary, the fabric color only slightly modifies the radiative properties in the spectral range concerned by radiative heat transfer and thermal protection.

2.4. **Effect of dyeing**

The dyeing is the process of adding color to the textile products. There are two dyeing modes involved in the fire intervention jacket manufacturing. The first consists in applying pigments during the polymer fiber production and then in weaving them to form the jacket. The second approach adds pigments after the jacket weaving.
Two different blue jackets (#1 and #2) with the two dyeing modes were compared (jacket #1 is a jacket dyed as a whole and jacket #2 is made of dyed fibers). Figure 6 presents the radiative properties for these jackets. The behavior of jacket #2 is close to be grey with an average absorptivity close to 90% (figure 6 (c)) while jacket #1 shows a weaker absorptivity, close to 80% in average.
Hence, the dyeing mode has a more important impact than the color itself, on the radiative properties of the jacket.



(a) Transmissivity ***(b) Reflectivity*** ***(c) Absorptivity***

Figure 6. Radiative properties of different two jackets with different dyeing mode

3. **Conclusions**

Radiative properties were measured over the visible-IR range for different Personal Protection Equipments used by firefighters. Results show that fire protective clothings have a high spectral absorptivity in the IR range (between 80 and 90%). This is an important observation since the heat absorbed will be transferred through the jacket by conduction. The thermal protection improvement would require a decrease of the absorptivity, using layers with higher reflectivity. The effect of the

fabric color on the radiative properties is not significant. However dyeing mode of the jacket may have a more important effect: a weakest absorptivity is observed for a dyed fiber jacket.
Future work will be focused on the heat transfer between personal protection equipment and the skin of a firefighter.

4. **References**

[1] J. Quintiere, Radiative Characteristics of Fire Fighters' Coat Fabrics, Fire Technology, Vol. 10 (2), pp. 153-161, 1974.

[2] A. Collin, A. Marchand, A. Kadi, Z. Acem, P. Boulet, J. Pageaux, S. Pinson, M. Lepelletier, Y. Van Waelfelghem, F. Magnolini and H. Charette. Study on visible-IR radiative properties of personal protective clothings worn during firefighting operations. Fire Safety Journal. Submitted. 2014.