Experimental and Theoretical Studies of the Influence of Surface Conditions on Radiative Properties of Opaque Materials

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Radiative properties of opaque materials strongly depend on their surface condition. The fabrication of superficial cavities of various forms and dimensions modifies the directional spectral emissivities or absorptivities. They are usually increased compared to those of optically smooth material; the gain depends on the material, the type of cavities, as well as the wavelength $\lambda$ and the direction $\Delta$ of the emitted or incident radiation. When grooves of dimensions larger than $\lambda$ are fabricated in a sample, the models, taking into account the successive reflections on their inner sides, give a good agreement with experimental data. But a similar theory does not explain the substantial increase of the infrared emissivity of ballblasted samples.

KEY WORDS: directional spectral emissivity; macroroughness; microroughness; mechanical surface treatments; radiative properties.

1. INTRODUCTION

Radiative properties of an optically polished opaque material depend only on its temperature $T$, for an incident or emitted flux characterized by a wavelength $\lambda$ and a direction $\Delta$. The adjective “opaque” means that the material does not transmit any fraction of the incident monochromatic electromagnetic radiation; more restrictively, the penetration depth is supposed to be macroscopically small (less than a millimeter). The expression “optically polished” applies to a surface, the roughness of which is characterized by dimensions such as quadratic average heights $\sigma$, much smaller.

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than the wavelength $\lambda$ of the considered radiation ($\sigma \ll \lambda$), and by surface wavelengths long compared to $\lambda$. For these opaque and almost perfectly plane materials, the directional spectral factors may be deduced from the values of the indices of refraction and extinction; for given $T, \lambda$, and $\Delta$, the emitted, reflected, or absorbed fluxes are readily determined.

In order to modify the radiative transfers, coatings may be applied that impose their own radiative characteristics. This happens spontaneously when oxide layers grow on the surface of heated metals. But the results are unforeseeable and not always in conformity with what was expected. Paints may be used to increase the emitted flux, for example; but ageing and adherence problems arise when the material is exposed to corrosive substances or subjected to temperature variations, etc.

Simple processes such as grooving (Section 3) or sandblasting (Section 4) produce cavities of diversified types. When their geometrical characteristics are larger than $\lambda$, the concept of "apparent" radiative properties can be introduced, which includes both emission and reflection on the inner sides of the cavities. In this paper, geometrical optics is used to compute these properties. The calculated values are compared with experimental results obtained with two experimental arrangements. Except for one case, the agreement is quite good. These processes may increase the hemispherical emissivities; they also allow the emission to be favored towards a given direction. Radiative transfers may be optimized, and no ageing problem occurs as the considered treatments are long-lasting, which is not the case for paints.

2. APPARENT RADIATIVE FACTORS OF A CAVITY

Let us recall that the radiative properties of an opaque material, the surface of which is optically smooth or slightly rough ($\sigma < \lambda$), are characterized by the following factors [1].

1. The directional spectral emissivity $\varepsilon_{\lambda}(\lambda, \Delta, T)$ is the ratio of the flux (Fig. 1) emitted by an elementary surface $dS$, in a solid angle $d\Omega$ around $\Delta$ and in the wavelength range $[\lambda, \lambda + d\lambda]$, to the one emitted by a blackbody under the same conditions. $\varepsilon_{\lambda}$ is a function of the wavelength $\lambda$, of the direction of emission $\Delta(\theta, \phi)$ (symbolically noted by a prime '), and of the temperature $T$ of $dS$.

2. If a flux is falling upon $dS$ from the direction $\Delta$ in the range $d\lambda$, the directional spectral absorptivity $\alpha_{\lambda}(\lambda, \Delta, T)$ represents the absorbed fraction and the directional-hemispherical spectral reflectivity $\rho_{\lambda}^\circ(\lambda, \Delta, T)$ represents the fraction reflected towards all directions of a hemispherical envelope covering $dS$, (notation $\circ$).