MEASURING THE NORMAL SPECTRAL INFRARED EMISSIVITY OF STRUCTURAL MATERIALS

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The emissivity of various structural materials was measured over the 2-10 μm range of wavelengths at temperatures from 50 to 200°C; the results are shown and their accuracy is evaluated.

The measurement of directional and, particularly, the normal spectral emissivity is of most interest where scientific and technical applications are concerned. With the value of this coefficient known, it is possible, for instance, to calculate the normal total emissivity [1] (the validity of such a calculation has been confirmed experimentally in [2]) and from this the hemispherical total emissivity [3]. Data on the spectral emissivity of materials at temperatures below 500°C are extremely scarce, however. Furthermore, the proposed methods of measurement have not been perfected yet and this presents an obstacle to their wider application in the evaluation of various materials with different properties. In order to make measurements by the method shown in [4], for example, the specimen must be shaped into a cylinder with a narrow slot in the wall. The dependence of test data on the ambient radiation determines the lowest specimen temperature, which should not be lower than 200°C. Two methods of measuring the spectral emissivity at lower temperatures have been proposed in [5]. Their gist is that, in order to eliminate the effect of ambient radiation, the measurements are made with a self-contained black body (at several slightly different temperatures) and with a system comprising two specimens and two black-body models pairwise at two different temperatures. The application of these methods evades the effect of ambient radiation, to be sure, but it also complicates the measurement procedure appreciably without eliminating the need for precise measurement and maintenance of the temperatures of both the specimens and the black-body models. In [6] the authors have proposed a procedure for measuring the normal spectral emissivity of opaque materials by means of two standard specimens, a "white" one and a "black" one, at the same temperature as the test specimen.

In this article we present the results of emissivity measurements pertaining to various structural materials, within the 2-10 μm range of wavelengths and at temperatures from 50 to 200°C, with a subsequent evaluation of their accuracy.

As has been shown in [6], the normal spectral emissivity of a specimen is determined according to the formula:

\[ \varepsilon = \frac{1}{1 - \varepsilon_w} \]

Fig. 1. Layout of standard specimens and test specimen in the heated yoke.

The standards and the test specimen are put in a heatable yoke, the latter having been designed so as to ensure that all specimens are at the same temperature. The location of all specimens on the front side of the yoke is shown in the dimensioned diagram in Fig. 1a; here item 1 is the "white" standard, item 2 is the test specimen, and item 3 is the "black" standard. For the "white" standard we used a gold disc with a smoothly polished surface. It is common knowledge [7] that gold is one of the metals almost perfectly resistant to oxidation in air when heated to rather high temperatures. The data on the spectral emissivity of gold were taken from [8]. For the "black" standard we used a model of an ideal black body, an assembly of rings of various diameters shown in cross section in Fig. 1b.

The surface temperature of the solid copper disc, heated in the yoke together with the test specimen and the other standard specimen, was measured with a platinum resistance thermometer as one arm of a model MVU-49 dc bridge circuit. The disc surface was scanned by the pad of a receiver-probe, to check whether the temperature distribution here remained uniform. This was ascertained by a constant output signal from that receiver-probe. The radiation receiver was a cooled (51 K) Ge-Hg photodiode for the 2-10 µm wavelengths and an uncooled PbS photodiode for the 1-3 µm wavelengths. The measuring apparatus is shown schematically in Fig. 2. A test specimen inside the heated yoke 1 was emitting radiation in the direction normal to its surface and this radiation was collected by a spherical mirror 2 (f = 300 mm, D = 150 mm), from there transmitted to another spherical mirror 3 (f = 500 mm, D = 210 mm), which then focused it on the pad of receiver 5. The yoke, the mirrors, and the receiver were positioned so that the receiver pad 1 mm in diameter would project on the specimen surface magnified 3-4 times. The radiation was made monochromatic by means of optical interference filters 4 with a 40-60% transmittivity and a relative pass-bandwidth $\Delta \lambda / \lambda_{\text{max}} = 0.05 \pm 0.01$ for the following peak-transmission wavelengths $\lambda_{\text{max}} = 1.80, 1.93, 2.12, 2.66, 3.30, 3.66, 3.85, 4.30, 4.68, 5.10, 6.13, 6.75, 7.66, 8.47,$ and 9.30 µm. The radiation was modulated at a frequency of 600 Hz. The modulator blades were enveloped by a shroud whose inside surface had been coated with soot. The output signals from the receiver were preamplified by a model V6-2 selective microvoltmeter and then recorded by a model V7-8 voltmeter.

We will now analyze the basic sources of errors, which determine the accuracy of measurements [6].

1. Imperfection of the Ideal-Black-Body Model. It is well known that the emissivity of a cavity depends on its shape and also on the degree of its nonisothermality. The emissivity of the ideal-black-body model made up of rings was calculated here on the basis of assuming very thin ring elements, relative to their radii. On this basis, the analog of our ideal-black-body model was an infinitely long groove of triangular cross section with a $10^\circ$ vertex angle. The spectral emissivity of points on the wall surface of such a groove at a distance $x_0$ from the vertex and at a temperature $T_{x_0}$ was not much different from the vertex temperature $T$ (operating temperature of the model) and was determined according to the formula which the authors had derived for diffuse reflection from groove walls with a spectral reflectivity $\rho \ll 1$:

$$
\varepsilon_{x_0}(\lambda) = (1 - \rho) \left[ 1 + \frac{\rho}{2} \left( \frac{\cos \alpha - x_0}{\sqrt{1 + x_0^2 - 2x_0 \cos \alpha}} \right) \right] 
+ \frac{c_2}{kT^2 \left[ 1 - \exp \left( -c_2/kT \right) \right]} \left[ \Delta T_{x_0} + \frac{\rho x_0 \sin^2 \alpha}{2} \int_0^1 \frac{(\Delta T_x - \Delta T_{x_0}) x dx}{(x^2 - 2x_0 x \cos \alpha + x_0^2)^{3/2}} \right].
$$

The wall width of a triangular groove is taken here as unity.

The temperature profile across the height of a ring element was determined experimentally. For this purpose, at three points (at the base, in the middle, and at the vertex) of an element were welded on copper-constantan thermocouples and their readings were recorded through a model R-308 potentiometer at various temperatures of the ideal-black-body model and various ambient temperatures $T_a$. The results have yielded the following relation: