METHOD OF BULK EXPERIMENTAL INVESTIGATION OF THE INTEGRATED HEMISPHERICAL EMISSIVITY OF A COATING

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UDC 536.3

An experimental method is considered that permits investigation of the temperature dependences of the integrated hemispherical emissivity for a large quantity of coatings simultaneously.

Determination of the emissivity of coatings is performed by the stationary method of comparing the coatings under investigation with a standard whose properties are assumed known. Coatings have thicknesses at which they are opaque to radiation. A diagram of the experimental apparatus is shown in Fig. 1. There is a vacuum chamber whose walls are blackened and cooled to cryogenic temperatures and there is also a regulatable infrared heater. The experimental specimens 1 are thin plates on whose face surface the coating to be investigated is deposited, while the standard coating is on the reverse side. Moreover, the standard specimens 2, on both of whose surfaces the standard coating has been deposited, are used in addition.

For the tests, the experimental and standard specimens are suspended in the chamber in one plane in checkerboard fashion. The infrared heater is mounted in a plane parallel to the side of the rear surface of the experimental specimens. The heater size and the spacing between it and the specimens are selected in such a way as to assure a uniform distribution of the radiant flux arriving at the specimen. The temperature of each specimen is measured in the tests that are conducted in a vacuum ($P \leq 10^{-4}$ mm).

In the stationary mode, the heat balance equations for the experimental and standard specimens are written, respectively, in the form

$$[\varepsilon_t(T_1) + \varepsilon_s(T_1)]\,\sigma T_1^4 = \alpha_s(T_1)\,E_{\text{inc}}, \tag{1}$$

$$2\varepsilon_s(T_2)\,\sigma T_2^4 = \alpha_s(T_2)\,E_{\text{inc}}. \tag{2}$$

We find from the combined solution of (1) and (2)

$$\varepsilon_t(T_1) = \frac{2\alpha_s(T_1)\,\varepsilon_s(\overline{T}_2)\,\overline{T}_2^4}{\alpha_s(\overline{T}_2)\,T_1^4} - \varepsilon_s(T_1), \tag{3}$$

where the arithmetic mean of the quantity T_2^4 of the standard specimens adjacent to the experimental specimen under consideration, or $\overline{T}_2^4$, is taken to raise the accuracy of the experiment. For instance, to determine the ε_t of the experimental specimen in the second row, third column (Fig. 1), the quantity is $\overline{T}_2^4 = (T_{\text{II-II}}^4 + T_{\text{I-III}}^4 + T_{\text{II-IV}}^4 + T_{\text{III-III}}^4)/4$, while for the specimen in the second row, first column it is $\overline{T}^4 = (T_{\text{I-I}}^4 + T_{\text{II-II}}^4 + T_{\text{III-I}}^4)/3$, etc

It follows from (3) that information about the radiation spectrum of the heater and the emissivity and absorptivity of the standard coating are necessary to determine $\varepsilon_t(T_1)$. A standard coating corresponding to a blackbody in its properties would be ideal. In practical cases, coatings whose radiation properties depend weakly on the temperature are of greatest interest as standards. Then it can be considered that $\alpha_s = \varepsilon_s$ when using the infrared heater whose radiation spectrum is relatively close to the radiation spectrum of the standard coating, and (3) is reduced to the form

$$\varepsilon_t(T_1) = \varepsilon_s(T_1)\left(\frac{2\overline{T}_2^4}{T_1^4} - 1\right). \tag{3'}$$

By varying the power delivered to the heater, different values of the radiant flux density can be obtained, and therefore, different specimen temperatures. The dependence $\varepsilon_t(T)$ is therefore obtained.

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 35, No. 4, pp. 628-632, October, 1978. Original article submitted November 9, 1977.

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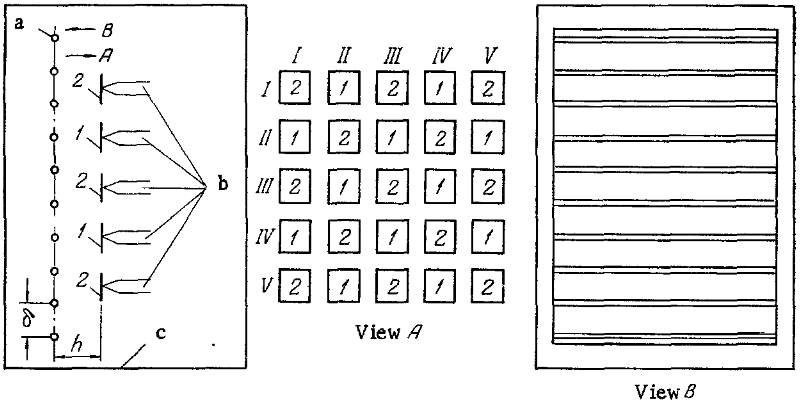

Fig. 1. Diagram of the experimental setup [a) heater; b) temperature sensors; c) vacuum chamber].

The absolute error in determining ε_t is found from the following expression obtained on the basis of (3') [1]:

$$\Delta\varepsilon_t=\left\{\left[\left(\frac{2\bar{T}_2^4}{T_1^4}-1\right)\Delta\varepsilon_s\right]^2+\left(\frac{8\varepsilon_s\bar{T}_2^3}{T_1^4}\Delta\bar{T}_2\right)^2+\left(\frac{8\varepsilon_s\bar{T}_2^4}{T_1^5}\Delta T_1\right)^2\right\}^{1/2}. \tag{4}$$

To analyze the error in the method, it is more convenient to represent (4) as

$$\frac{\Delta\varepsilon_t}{\Delta\varepsilon_s}=\left[\left(\frac{2\bar{T}_2^4}{T_1^4}-1\right)^2+\left(\frac{8\bar{T}_2^3}{T_1^3}\cdot\frac{\varepsilon_s}{\Delta\varepsilon_s}\cdot\frac{\Delta\bar{T}_2}{T_1}\right)^2+\left(\frac{8\bar{T}_2^4}{T_1^4}\cdot\frac{\varepsilon_s}{\Delta\varepsilon_s}\cdot\frac{\Delta T_1}{T_1}\right)^2\right]^{1/2}. \tag{4'}$$

Let us examine the terms in the right-hand side of (4'). It follows from (1) and (2) that the first term diminishes with the rise in the quantity ε_s. If a standard coating is used for which $T_1 \geq T_2$ is almost one, then $(2\bar{T}_2^4/T_1^4 - 1) \leq 1$. The errors in measuring the temperature by using thermocouples and recording instruments of a high class of accuracy are, according to [2], $\Delta T_1/T_1 \approx 0.05$-$0.1\%$ for the experimental specimens and $\Delta\bar{T}_2/\bar{T}_2 \approx 0.1$-$0.2\%$ for the standards (taking into account the method of determining the quantity $\bar{T}_2^4$). The errors in determining the emissivity of the standard coating is $\Delta\varepsilon_s/\varepsilon_s \approx 2$-$5\%$ [3]. Terms II and III are therefore similar in magnitude and equal ≈0.02-0.05.

Taking the exposition above into account, it is seen that the error in determining the emissivity of the coatings under investigation in a mass experiment in the method under consideration is practically equal to determining the emissivity of a standard coating in a unique experiment.

Tests were conducted in conformity with the method elucidated above, whereupon the temperature dependences $\varepsilon_t(T)$ were obtained simultaneously for seven coatings in the temperature range $-100°C \leq t \leq +200°C$. The enamel AK-512 (black) was used as standard.

The experimental and standard specimens were plates of the aluminum alloy AMG-6, of 50 × 50 mm size and $\Delta = 0.5$ mm thickness. They were connected to two Chromel–Copel thermocouples, one of which was at the center while the other was at the periphery along the specimen diagonal, at 18 mm from the center. The prepared specimens were suspended by fine Nichrome threads (⌀ 0.1 mm) through heat-insulating bridges to a metal frame in three series of five specimens each. A flat infrared heater, whose size was 1.5 times greater than the size of the provisional working area in which the specimens were placed, was located at a distance of $h = 50$ mm from the plane of the specimens. It was a set of 3 mm diameter Nichrome rods, separated by $\delta = 20$ mm, and heated by an electrical current. The system of heater and frame with specimens was placed in the vacuum chamber, as shown in Fig. 1. The interior walls of the chamber had a ribbed surface, were coated by the black enamel AK-512, and were cooled by liquid nitrogen. The tests were conducted in the following sequence. After the vacuum chamber had reached the working mode ($P < 10^{-4}$ mm Hg, $T_w = 80°K$), electrical power corresponding to the thermal mode of the specimens with the minimum temperature $t = -100°C$ was delivered to the heater. While the specimens were reaching the stationary mode, their temperatures were taken every 15 min. The stationary mode was determined by the last three readings when the specimen temperature in the first and third readings differed by not more than 1°. After the temperature buildup, the passage to the next mode was realized in all the specimens. Seven modes were established during the tests. The last maximum mode was constrained by the greatest achievable temperature $t = +200°C$ in the specimen with the minimum value of emissivity.

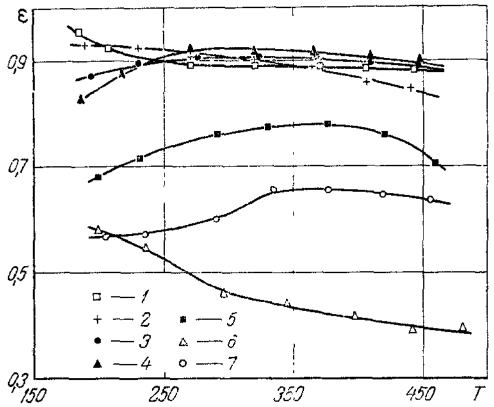

Fig. 2. The dependences $\varepsilon_t = f(T)$ obtained in experiment [1) enamel AK-512 white + OSO-C; 2) enamel AK-512, green; 3) enamel AK-512 white; 4) enamel KO-512; 5) KO-538 lacquer; 6) enamel KO-96; 7) lacquer ML-255].

The readings of both thermocouples in all the specimens agreed during the experiment. The radiant flux distributions in the working area, obtained on the basis of readings on the standard specimens, can be considered sufficiently uniform. The discrepancy between the quantities $\overline{T}_2^4$ set in the computation of T_2^4 did not exceed 1.8% for all the experimental specimens. Taking account of the continuity and smoothness of the changes in the radiant flux density from the heater resulting from the laws of radiant heat transfer, the errors in determinining $\overline{T}_2^4$ were less than 1%.

The emissivity of the coatings under investigation was calculated by means of (3), in which $\varepsilon_s = 0.95$; T_1, T_2 were substituted; the T_1 and T_2 were measured in the experiment, where the quantity $\overline{T}_2^4$ was determined by the abovementioned method. Taking into account $\delta\varepsilon_s \approx 4\%$, the error in the experiment was $\delta\varepsilon_t \approx 4.5$-6%. The results obtained are represented in Fig. 2 in the form of experimental points and their approximate dependence $\varepsilon = f(T)$ is explained by the fact that the experimental specimens had dissimilar temperatures for a constant, particulary minimum and maximum, power delivered to the heater because of the difference in ε_t.

NOTATION

ε	is the integrated hemispherical emissivity of the coating;
α	is the absorptivity of the coating relative to heater radiation;
T	is the temperature;
σ	is the Stefan–Boltzmann constant;
E_{inc}	is the density of the incident radiant flux from the heater;
P	is the pressure.

Subscripts

t	is the coating under investigation;
s	is the standard coating;
1	are the experimental specimens;
2	are the standard specimens;
w	are the chamber walls.

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