SPATIAL DISTRIBUTION OF RADIATION FROM OXIDIZED HEAT-RESISTANT ALLOYS

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UDC 563.3

It is shown that the type of angular distribution, the absolute values of directional emissivity, and the degree of polarization of radiation from heat-resistant alloys depend significantly on oxidation conditions.

Uniform heating of items in a furnace is determined mainly by the distribution of local thermal fluxes which depend on the spatial distribution of radiation from both sources of thermal energy and the heated metal itself. During heating in air or other oxidizing media, oxidation occurs on the surface of the heater, of the outer thermal screen, and of the metal, which produces a change in the spatial distribution of radiation. It was experimentally shown [1-3] that the shape of the characteristic radiation curve for highly oxidized metal surfaces was similar to the angular distribution of the directional emissivity ε_φ of dielectrics, with the nature of the dependence $\varepsilon_\varphi = f(\varphi)$ changing continuously during heating. Unfortunately, the data obtained in the works cited do not make it possible to establish the general nature of the effect of the oxidation state on a metal surface on the spatial distribution of its radiation. The authors obtained data for the effect of oxidation time and temperature on the spatial distribution of radiation from certain heat-resistant alloys extensively used in the construction of electric furnaces.

A radiation method [4] of adequate accuracy and simplicity was used to study the spatial distribution of the radiation. Measurement of directional emissivity was carried out by comparison between the spectral or integral intensity of sample radiation and the intensity of radiation from a standard calibrated against a model of an absolute black body.

A sample in the form of a sheet 200 × 400 × 0.5 mm in size was installed between the current leads to the heating chamber. The upper current lead could be shifted in a direction which eliminated sample bending because of thermal expansion through the action of tensile forces created by the springs of a stretching mechanism. The construction of the current leads made it possible to shift them relative to the optical system for correction of sample position and alignment of the system.

The guides and current leads with the installed sample were mounted on a special turntable permitting rotation of the sample around an axis. Measurement of the angle of rotation was made with a rotating mechanism. The accuracy in the measurement of the angle of rotation was 0.5°.

To avoid sample oxidation while emissivity was being measured, the heating chamber was first purged with purified argon. Measurement of sample temperature was accomplished by means of two Chromel–Alumel thermocouples with electrodes 0.2 mm in diameter. The junction of the thermocouple passed through an opening in the sample and was attached to the test surface at a distance of 2-3 mm from the area of observation.

Electrodes were led out on the opposite side of the sample and lay parallel to the plane of the sample. The electrodes were insulated with a refractory coating made of magnesite powder and water glass. The appearance of an oxide film on the surface of a sample introduces a certain error in the measurement of the surface temperature by the method described above. As shown by calculation, however, the temperature drop over the thickness of a 2-mm oxide film does not exceed 1°.

Moscow Institute of Steels and Alloys. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 29, No. 3, pp. 463-468, September, 1975. Original article submitted August 29, 1974.

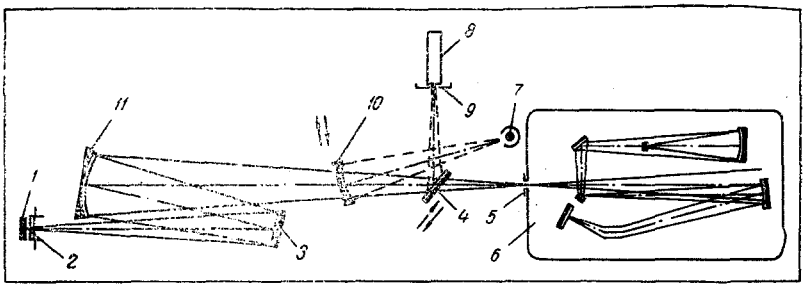

Fig. 1. Optical arrangement for measurement: 1) sample; 2) CaF_2 plate; 3) plane mirror; 4) plane Al mirror; 5) entrance slit of monochromator; 6) IKS-12; 7) globar; 8) vacuum radiation thermoelement; 9) diaphragm; 10, 11) parabolic mirrors.

A sheet of Kh20N80 alloy oxidized for 20 h at 1200°C was used as the standard for comparison. The size of the standard was the same as that of a sample. As shown by numerous tests, the emissivity of the standard remained practically unchanged under subsequent heating. The temperature of the standard was measured in the same way as the temperature of a test sample. The standard was installed in the heating chamber at the test-sample position and calibrated against a model of an absolute black body.

For measurement of angular distribution of spectral emissivity, the radiation flux at the exit of the heating chamber was focused on the entrance slit of an IKS-2 monochromator spectrometer (Fig. 1). The parabolic mirror 11 was diaphragmed in order to reduce the aperture angle; this made it possible to increase the angular resolution of the device.

The selected parameters of the optical system made it possible to study the radiation properties of the samples in the angular range from 0 to 85° from the normal. Within these angular limits, the image of the sample projected in the direction of the principal optical axis of the device covered the entire width of the spectrometer slit, which made it possible to avoid the introduction of corrections for nonisothermicity of the sample and for radiation from the edges.

In measurements of directional integral emissivity, the intensity of radiation from sample and standard was measured by means of a vacuum radiation thermoelement operated in conjunction with a P-303 high-resistance potentiometer and an M 195/1 reflection galvanometer.

An estimate of the error in measurement of sample emissivity was made which included such sources of error as imperfection in the model of an absolute black body, errors in the measurement of the temperatures of the sample and of the model of an absolute black body, the effect of background, flaws in the optical system, errors in the measurement of the effective wavelength of the spectrometer, nonlinearity of the radiation detector and amplifier, etc. The magnitude of the errors depends on wavelength and temperature. At a sample temperature of 1200°K, the total error in the measurement of integral emissivity was 4.2%; it was 5% at 1000°K and 6% at 800°K.

Integral and spectral directional emissivities of Kh20N80, Kh15N60, Kh18N9T, ÉI-696, ÉI-952, and ÉI-626 alloys were studied.

At sufficiently long oxidation times and high temperatures (for example, 20 h at 1000°C), the angular distribution of the radiation from all materials studied corresponds to the characteristic radiation curves for dielectrics. A decrease in the integral emissivity of a surface occurs at angles of deviation from the normal $\varphi > 40°$; the most marked reduction in the values of $\varepsilon_{\Sigma\varphi}$ were observed for $70 < \varphi < 90°$ (Figs. 2a, b).

It is interesting to note that the spatial distribution of the radiation from all alloys studied changed continuously in the course of heating. For the Kh15N60 alloy, for example, the radiation from the oxidized surface corresponds more to the radiation from a metal than that from a dielectric for heating times up to 4 h (Fig. 2). It is clear from Fig. 2a that the main increase in emissivity with increase in heating time takes place at angles close to the normal. The data obtained indicate that the integral emissivity of Kh15N60 alloy even when heated for only 1 h nearly reaches a maximum value for $\varphi > 50°$ and remains practically unchanged as the duration of heating is increased. At angles closer to the normal, the increase in the values of the directional integral emissivity $\varepsilon_{\Sigma\varphi}$ continued over a longer period of time.

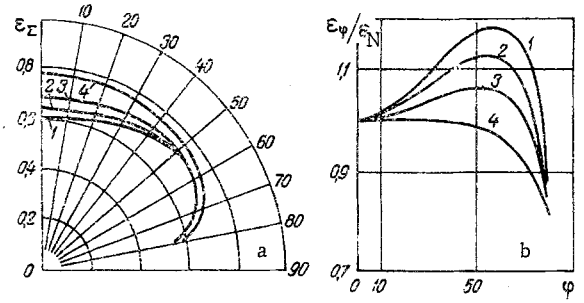

Fig. 2. Effect of oxidation time on angular distribution of integral emissivity of Kh15N60 alloy (oxidation temperature, 800°C; φ, angle from the normal): 1) 1 h; 2) 2 h; 3) 4 h; 4) 20 h.

Most likely, the increase in emissivity from a slightly oxidized surface for deviation of the radiation from the normal is explained by the difference in the thickness of the oxide film in the normal and oblique directions. When a thin oxide film is formed, the radiation properties of the oxidized metal surface in the direction of the normal are determined by the characteristics of both the oxide layer and the metal substrate. For directions other than normal, the role of the radiation from the oxide, which has higher values of emissivity, in the effective radiation from the oxide–metal system increases, and the radiation from the oxidized surface at angles greater than 50-60° is determined mainly by the radiation properties of the oxide layer. This type of effect of heating duration on the spatial distribution of spectral and integral emissivity was also noted in [3]. The time dependence obtained for the variation of characteristic radiation curves (Fig. 2) is typical of all samples studied.

The nature of the spatial distribution of radiation depends strongly on the wavelength of the radiation. In this work, the spatial distribution of the spectral emissivity was measured for oxidized surfaces of Kh20N80, Kh15N60, and ÉI-626 alloys.

Figure 3 presents the results of a study of the effect of the oxidizing heating mode on the spatial distribution $\varepsilon_{\lambda\varphi}$. A test sample of Kh15N60 alloy was oxidized for 20 h at 800, 900, and 1000°C. The results show that the nature of the spatial distribution of the radiation properties of the sample changes significantly with an increase in heating temperature and, consequently, in the thickness of the oxide film. It is interesting to note that considerable difference in the nature of the $\varepsilon_{\lambda\varphi}/\varepsilon_{\lambda N}$ curves for radiation of different wavelengths is observed in the case of the sample oxidized at 800°C. Thus, while the directional emissivity of radiation with a wavelength $\lambda = 2\,\mu$ decreases as the angle between the normal to the surface and the direction of the radiation increases (which is typical of samples with a thick oxide film), an increase in values of $\varepsilon_{\lambda\varphi}/\varepsilon_{\lambda N}$ at $\varphi > 50°$ is noted in comparison with the spectral emissivity in the direction of the normal for radiation at wavelengths of 6 and 8 μ. Furthermore, the values of $\varepsilon_{\lambda\varphi}/\varepsilon_{\lambda N}$ in this angular range decrease as one goes to shorter wavelengths. This type of spatial distribution for spectral emissivity probably can be explained by the fact that an oxide layer of given thickness possesses greater transparency for infrared radiation at longer wavelengths. With an increase in heating temperature and thickening of the oxide film, the radiation from a metal surface approximates the radiation from dielectrics and the values of the ratio $\varepsilon_{\lambda\varphi}/\varepsilon_{\lambda N}$ begins to fall in the angular range mentioned above. It is interesting to note that the characteristic radiation curves for samples oxidized at 900°C are similar to the characteristic radiation curves for examples with sufficiently thick oxide films. Nevertheless, the curves obtained for the wavelengths 4, 5, 6, and 8 μ lie above the curve representing the ratio $\varepsilon_{\lambda p}/\varepsilon_{\lambda N}$ at 2.0 μ, which indicates a definite transparency of the oxide film for infrared radiation having a wavelength greater than 2 μ.

There is great interest in the effect of length of heating on the spatial distribution of spectral emissivity. Studies of this kind were made with Kh20N80 alloy samples. After cold rolling, the samples were oxidized without additional surface treatment directly in the heating chamber at 1000°C. Since the time to measure the spatial distribution of radiation for a single wavelength did not take more than 1-2 min, the measurements were made directly during the course of the heating. The nature of the relationships $\varepsilon_{\lambda\varphi} = f(\varphi)$ and $\varepsilon_{\lambda\varphi}/\varepsilon_{\lambda N} = f(\varphi)$ for the wavelengths 4.5, 6, and 8 μ are similar (Fig. 4) to the corresponding relations for dielectrics, although the low values of $\varepsilon_{\lambda\varphi}$ are evidence of satisfactory transparency of the oxide film to infrared radiation.

Most likely, this kind of spatial distribution of spectral emissivity is explained by the fact that the thickness of the oxide film formed on the metal surface is so slight that it does not have a significant effect on the radiation from the metal surface even at angles close to 90° from the normal.

It should be noted that the sharp rise in values of $\varepsilon_{\lambda\varphi}$ for $\varphi = 70$-$80°$ typical of polished metals was not observed in the present work and the directional emissivity decreased monotonically as the radiation angle increased. This can be explained by the fact that the surface of the test-alloy samples selected after

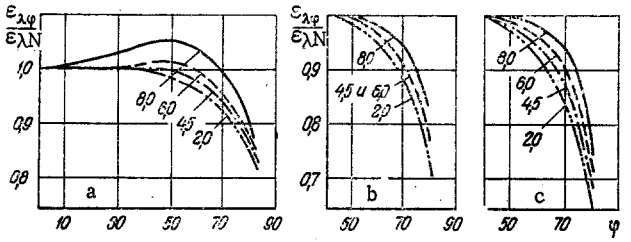

Fig. 3. Effect of oxidation temperature on angular distribution of spectral emissivity for Kh15N60 alloy. Samples oxidized for 20 h at t of: a) 800°C; b) 900°C; c) 1000°C. Numbers on the curves denote wavelength λ, μ.

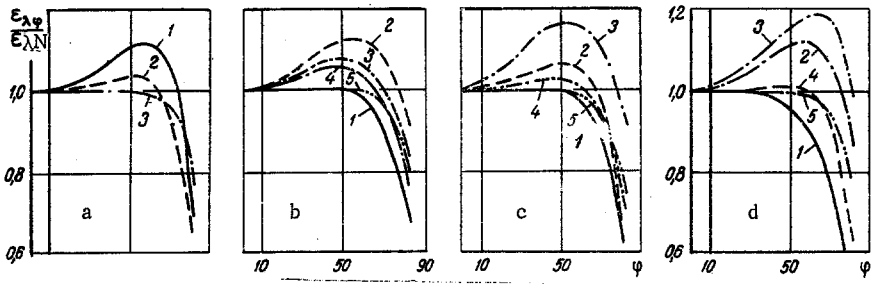

Fig. 4. Effect of length of oxidation on angular distribution of radiation from Kh20N80 alloy: [1) 30 min; 2) 1 h; 3) 2 h; 4) 3 h; 5) 6 h]. a) λ = 2 μ, 3) 3h; b) λ = 4.5 μ; c) λ = 6 μ; d) λ = 8 μ.

rolling was of considerable roughness in comparison with a polished metal and, as shown [5], even a small increase in roughness of a metal surface leads to a sharp decrease in the values of $\varepsilon_{\lambda\varphi}$ in the angular range at 70-80° from the normal.

The relative directional emissivity $\varepsilon_{\lambda\varphi}/\varepsilon_{\lambda N}$ increases in proportion to thickening of the oxide layer, reaching maximum values after some time where the length of this time interval is different for radiation of different wavelengths. After reaching maximum values at $\varphi = 60°$, the ratio $\varepsilon_{\lambda\varphi}/\varepsilon_{\lambda N}$ begins to fall because of the rise in the spectral emissivity $\varepsilon_{\lambda N}$ in the direction of the normal. Furthermore, the spatial distribution of the emissivity approximates the distribution from dielectrics.

It is well known that the radiation from polished metal is highly polarized at angles $\varphi > 80°$ from the normal, while the radiation from a highly oxidized surface is practically unpolarized. There is therefore great interest in the nature of the change in polarization properties of radiation from a metal during oxidation of its surface.

A polarizer (indium film on a quartz backing) was installed in front of the window of the heating chamber for studies of the polarization properties of an oxidized surface. Studies were made of the effect of the degree of oxidation of a metal surface on the angular distribution of the parallel and perpendicular components $B_{\parallel}$ and $B_{\perp}$ of polarized radiation and of the degree of polarization P of initially unpolarized radiation from ÉI-626 alloy samples with a polished surface oxidized at 600, 1000, and 1100°C for 2 h. The studies showed that with an increase in oxidation temperature, the relative brightness of unpolarized radiation increased at angles other than the normal. When the oxide layer thickened, the values of the relative brightnesses of the components of polarized radiation were considerably different, although the degree of polarization decreased.

Thus the results indicate that radiation from oxidized metal surfaces depends strongly on the direction of radiation. Surface roughness, thickness of oxide film, and spectral range of radiation have a strong effect on the nature of the angular distribution and on the absolute values of the directional integral and spectral emissivities.

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