Thus, the length over which impregnation occurs is directly proportional to the pulling velocity and inversely proportional to the pressure difference. The number $R\beta(5-2n)/36\alpha$ characterizes the increase in this length due to the initial pressure gradient.

NOTATION

v_r, radial filtration velocity; u, R, k, and ε, pulling velocity, radius, permeability, and porosity of the cylindrical filler; p_f, p_0, pressure of the liquid at the boundary with the filler and air pressure in its pores; T_f, T_0, corresponding temperatures; μ_f, μ_0, viscosities of the liquid at the temperatures T_f and T_0; j_f and j_0, initial pressure gradients at these temperatures: δ, thickness of the impregnated part of the filler.

LITERATURE CITED

1. Yu. A. Buevich and V. A. Kalinnikov, "Impregnation of a heated filler with a viscous liquid," Inzh.-Fiz. Zh., 36, No. 6, 997-1004 (1979).
2. A. Kh. Mirzadzhanzade, Problems of the Fluid Dynamics of Viscoplastic and Viscous Liquids and Applications in Oil Recovery [in Russian], Aznefteizdat, Baku (1959).
3. J. I. Frenkel, Kinetic Theory of Liquids, Peter Smith (1972).

EMISSIVITY OF STEELS AND ALLOYS IN THE SPECTRAL REGION 2-13 μm

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UDC 536.3

The spectral emissivity of steels and alloys in the temperature range 700-900°K is experimentally studied.

Data on the spectral emissivity of structural materials is used as the initial data in present methods of calculating radiative heat transfer. Due to the complexity of the experiments and the great range of materials, such data is available only for a small number of grades.

Here we experimentally study the normal spectral emissivity of steels and alloys 40Kh2N-2MA, 38KhN3MA, 12Kh1MF, ÉP-182, 08Kh18N10T, St3sp, ÉI-712, 09G2S, steel 20, 1Kh18N10T, and D16AT during heating in air.

The experimental unit was based on an IKS-14A spectrophotometer operated in the double-beam mode. A diagram of the unit is shown in Fig. 1. The flow of heat radiation from the test material 8 was directed into the specimen channel, while the radiative heat flow from a thin-walled cylindrical model of a blackbody was directed into the comparison channel. The specimen and model were heated by an electric furnace 4. The temperatures of the radiating cavity of the blackbody and specimen were measured with Chromel–Alumel thermocouples with a thermoelectrode diameter of 0.2 mm. The readings of the thermocouples were calibrated with a standard PR-30/6 thermocouple. Additional measurements of the temperature of the radiating cavity of the blackbody were obtained with a TERA-50 radiation pyrometer. The thermo-emf was recorded with VK2-20 digital electronic voltammeters and an R363-2 dc potentiometer of accuracy class 0.002. To reliably measure the specimen temperature, the thermocouples were either caulked into the specimen or welded to it so that the surface of the thermocouple junction was flush with the radiating surface of the specimen.

The optical system of the IKS-14A spectrophotometer, including the double-beam light source, was left unchanged. This allowed us to better adjust and check the monochromator and the recording part of the instrument before the tests. During final adjustment of the unit, the heat flows in both channels were equalized by recording the radiation from a second, graphite model of a blackbody. When the temperatures of the blackbody models in the first and second channels were equal, the measured flows of heat radiation for these channels were also equal and the recorder of the spectrophotometer showed 100% transmission.

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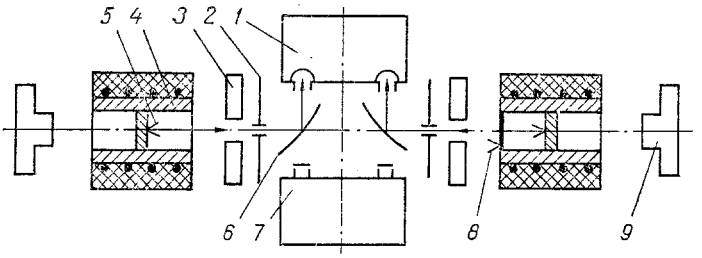

Fig. 1. Basic diagram of the unit for measuring the spectral emissivity of structural materials: 1) monochromator and recording part of an IKS-14A spectrophotometer; 2) diaphragm; 3) protective water-cooled shield; 4) tubular electric furnace; 5) thermocouple; 6) parabolic mirror; 7) light source; 8) specimen; 9) TERA-50 pyrometer.

TABLE 1. Condition of the Surface of the Specimens after Holding at 800°K in Air for 5 h

Specimen material	Roughness parameters	
	Ra, μm	Rm, mm
1Kh18N10T	12	0,42
Steel 20	8	0,50
09G2S	7,5	0,20
EI-712	7	0,25
EP-182	6	0,14
12Kh1MF	5	0,12
St3sp	4	0,12
38KhN3MA	2,5	0,1
40Kh2N2MA	1,5	0,15
08Kh18N10T	0,5	0,05
D16AT	Below 0,5	—

A very complicated operation during the tests was regulating and maintaining the equality of the temperatures of the cavity of the blackbody and the surface of the specimen. It was shown in [1] that this operation can be eliminated and the experiment made less time-consuming if some simplifications are made in obtaining the measurements. The essence of this approach is as follows. If we use S_1 and S_2 to designate the reactions of the radiation detector of the spectrophotometer to the heat flows coming from the first and second channels, we can write:

$$S_1 n = \varepsilon_\lambda(T_0) E_\lambda(T_0) + R_\lambda E_\lambda(T_b), \tag{1}$$

$$S_2 n = E_\lambda(T^0) D_\lambda + R_{\lambda_w} E_\lambda(T_b) + \varepsilon_{\lambda_w} E_\lambda(T_b). \tag{2}$$

It is known from the principle of operation of a double-beam spectrophotometer that at each moment of time the radiant fluxes incident on the detector are equalled out in both channels by the photometric wedge. Taking into account that $\varepsilon_{\lambda w} = a_{\lambda w}$ and $R_{\lambda w} + \varepsilon_{\lambda w} = 1 - D_\lambda$, from the equality of Eqs. (1) and (2) we obtain

$$\varepsilon_\lambda(T_0) = D_\lambda [E_\lambda(T^0) - E_\lambda(T_b)]/[E_\lambda(T_0) - E_\lambda(T_b)]. \tag{3}$$

If $T^0 = T_0$ in the last expression, we obtain $\varepsilon_\lambda(T_0) = D_\lambda$, i.e., the spectrophotometer directly records spectral emissivity. When the temperatures of the blackbody T^0 and specimen T_0 are not equal, the determination of ε_λ can be reduced to measurement of the parameters D_λ, T^0, and T_0 and we can ignore $E_\lambda(T_b)$:

$$\varepsilon_\lambda(T_0) = D_\lambda [\exp(C_2/\lambda T_0) - 1]/[\exp(C_2/\lambda T^0) - 1]. \tag{4}$$

The differences in the values of ε_λ with the use of Eqs. (3) and (4) are on the order of 0.001 for $T^0 = 880$°K, $T_0 = 900$°K, $T_b = 300$°K, $\lambda = 4.0$ μm.

The emissivity of the materials is appreciably affected by the condition of the radiating surface, which is characterized by the level of oxidation and roughness. To prevent an

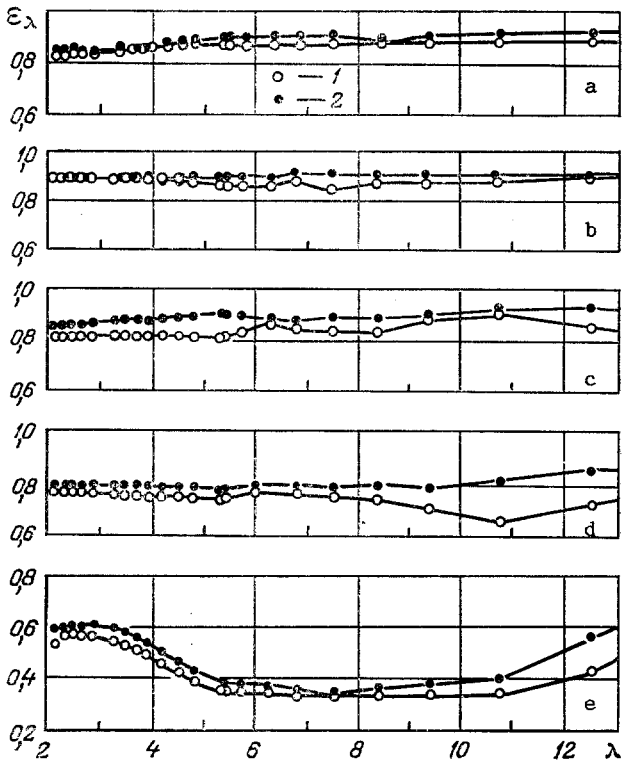

Fig. 2

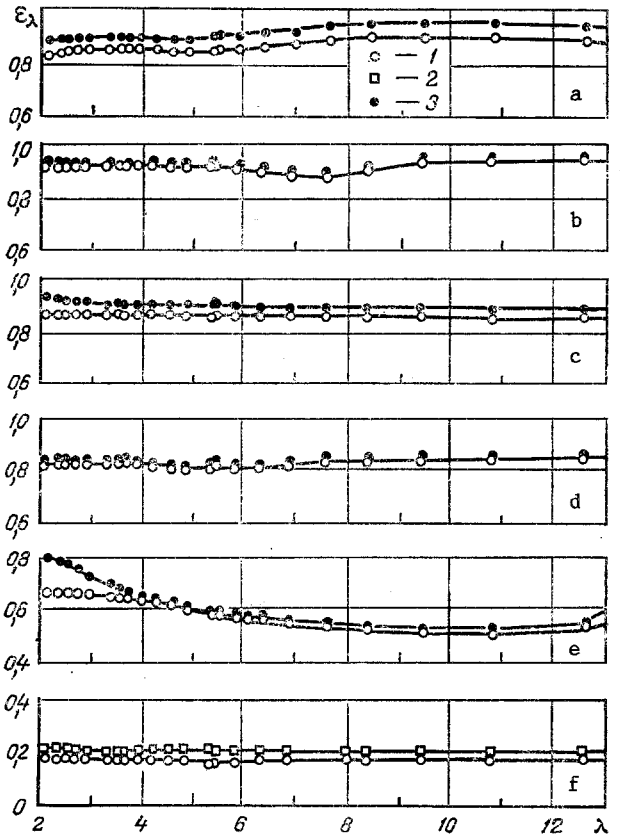

Fig. 3

Fig. 2. Spectral emissivity of steels 40Kh2N2MA (a), 38KhN3MA (b), 12Kh1MF (c), ÉP-182 (d), and 08Kh18N10T (e) in relation to wavelength and temperature: 1) 700°K; 2) 900°K. λ, μm.

Fig. 3. Spectral emisivity of steels and alloys St3sp (a), ÉI-712 (b), 09G2S (c), steel 20 (d), 1Kh18N10T (e), and D16AT (f) in relation to wavelength λ and temperature: 1) 700°K; 2) 800°K; 3) 900°K.

oxide film from forming during the tests, the specimens were oxidized beforehand in air at 800°K for 5 h. We then measured the surface roughness of the specimens on an MIS-11 binary microscope. Surface roughness was described with the parameters Ra and Rm. The values of these parameters for the test specimens are shown in Table 1.

The results obtained for spectral emissivity for different wavelengths and temperatures are shown in Figs. 2 and 3. It is evident from the graphs that the emissivity of most of the specimens changes little in relation to wavelength. The exceptions are steels 08Kh18N10T and 1Kh18N10T. These steels show a large change in spectral emissivity in the spectrum interval 3-6 μm. The difference between the emissivities of these steels in the intervals 2-3 μm and 7-12 μm averages 0.2. Such a change in emisivity is in all probability attributable to the thinness of the oxide film. It is known that the emissivity of oxides is an order greater than that of metals. The thickness of the oxides on steels 08Kh18N10T and 1Kh18N10T is sufficient to generate shortwave radiation in the spectral interval 2-3 μm but is insufficient to do the same in the interval 7-12 μm. The heat flow for the latter is formed against the background of the radiation of the metal base.

The fact that the emissivities of the steel 1Kh18N10T specimen are higher than those of 08Kh18N10T are due to greater roughness (see Table 1). The chemical composition of these steels differs in terms of carbon content by 0.02%, and this difference has almost no effect on emissivity.

The general tendency for all of the alloys is for emissivity to increase with an increase in temperature. Here, no change takes place in the character of the dependence of emissivity on wavelength.

The results on the emissivity of steel 1Kh18N10T were compared with the data in [2] (Table 2) obtained for specimens after oxidation in air over 5 h at 600°K. It can be seen from the comparison that the results agree well within the experimental error.

TABLE 2. Comparison of the Data Obtained on Spectral Emissivity for Steel 1Kh18N10T with the Results in [2]

Source	λ, μm						
	3	4	5	6	7	8	9
Present study	0,70	0,63	0,60	0,57	0,56	0,51	0,50
[2]	0,75	0,65	0,59	0,55	0,51	0,49	0,48

Thus, it was established that oxidized steels and alloys 40Kh2N2MA, 38KhN3MA, 12Kh1MF, ÉP-182, St3sp, ÉI-712, 09G2S, steel 20, D16AT radiate as graybodies at temperatures of 700-900°K in the spectral interval 2-13 μm. The radiation of steels 08Kh18N10T and 1Kh18N10T in th is interval is of a selective character. The emissivity of all of the investigated specimens increases with an increase in temperature.

The error of measurement of spectral emissivity was ±5.2%.

NOTATION

S_1 and S_2, reactions of the radiation detector to heat flows in the first and second channel; n, proportionality factor between the heat flows and the reaction of the detector; ε_λ, spectral emissivity of the specimen; T_0, T_b, T^0, temperatures of the specimen, background, and blackbody; E_λ, spectral radiation density of the blackbody; D_λ, transmission factor of the photometric wedge of the spectrophotometer; R_λ and $R_{\lambda w}$, spectral reflectivities of the specimen and wedge; C_2, second constant of Planck's law; λ, wavelength of the radiation; Ra, arithmetic mean of the deviation of the surface roughness; R_m, mean step of the surface roughness.

LITERATURE CITED

1. L. S. Slobodkin and Yu. M. Sotnikov-Yuzhik, "Measurement of the monochromatic emissivity of coatings at 100-400°C," Inzh.-Fiz. Zh., 27, No. 2, 203-207 (1974).
2. V. M. Sedelkin and B. M. Khoron, "Study of the emissivity of tubes of heat-resistant steels," in: Calculation, Design, and Use of Radiation Tubes in Industry [in Russian], Naukova Dumka, Kiev (1977), pp. 127-132.

INTERNAL FRICTION AND COEFFICIENT OF LINEAR EXPANSION OF ZIRCONIUM AND COBALT IN THE PHASE TRANSITION REGION

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UDC 539.67

Results are presented from measurement of the internal friction and coefficient of linear expansion of zirconium and cobalt near the points of first-order phase transformation. This is the hcp ↔ bcc transition beginning at 1135°K for zirconium and the hcp ↔ fcc transition beginning at 706°K for cobalt.

Tests were conducted to measure internal friction by recording the resonance frquency and bending-vibration amplitude of a disk-shaped specimen at different temperatures up to the phase-transition point T'. The experimental unit was the same as described in [1]. We took measures to ensure the same temperature at all points of the specimen. The measurements were made at fundamental frequencies on the order of 100 kHz (one of these frequencies corresponded to a nodal line in the form of a circle, while for the second frequency the nodal line was located along two mutually perpendicular diameters). The coefficient of linear expansion was measured on a dilatometer made by the firm ULVAK SINKU RIKO. The

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