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 this 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.

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

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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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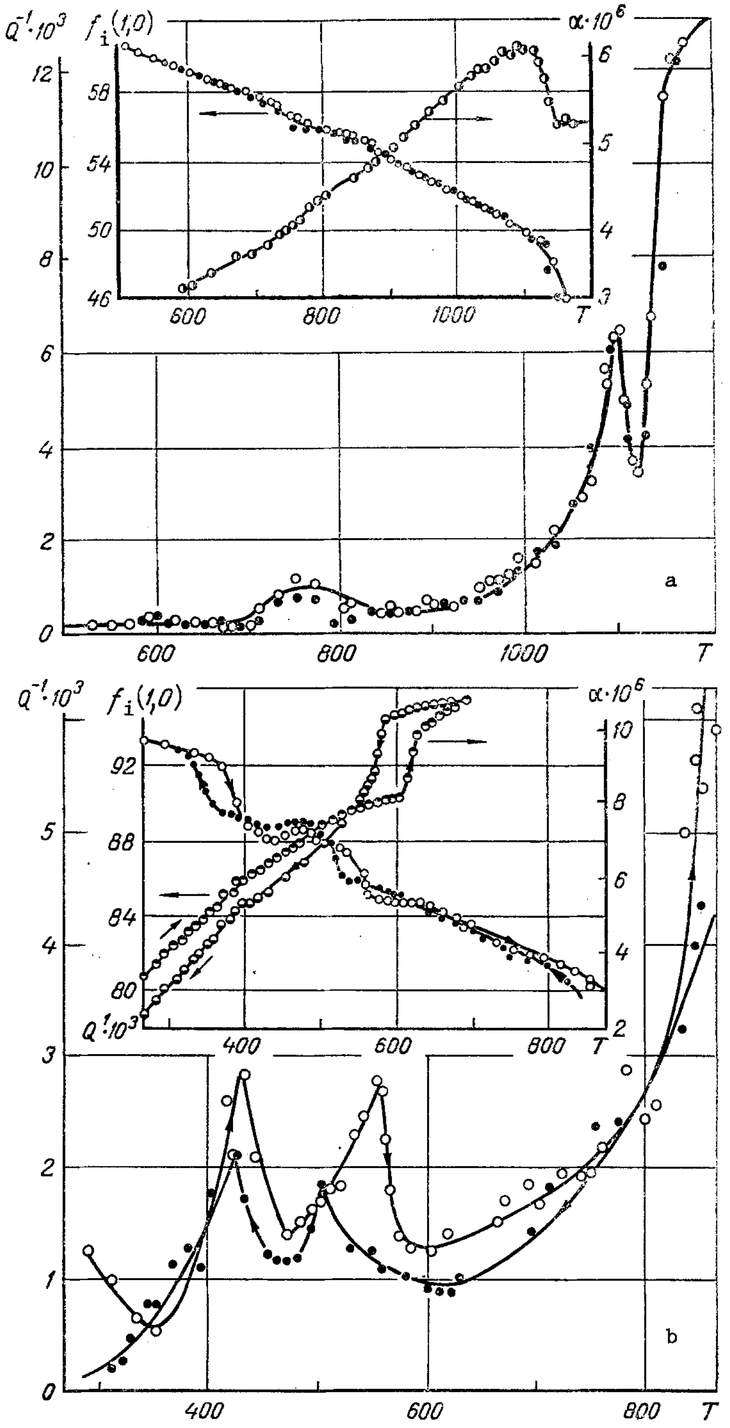

Fig. 1. Internal friction and the coefficient of linear expansion of zirconium (a) and cobalt (b) ($Q^{-1}\cdot 10^3$ is the dimensionless value; T, °K; f_i (1.0), kHz; $\alpha\cdot 10^6$, K^{-1}).

specimens were prepared from zirconium iodide and electrolytic cobalt. The purity of the specimens was 99.95 and 99.9, respectively.

The internal friction was calculated from the formula $Q^{-1} = 2\Delta F/F$, where F is the resonance frequency of the bending vibrations of the disk-shaped specimen; ΔF is the difference in the frequencies of the resonance curve at points with the ordinate 0.707 compared to the maximum.

The numerical value of internal friction is determined by the amount of energy dissipation and is connected in the phase-transition region with the degree of deviation of a parameter of the order η from its equilibrium value η_0; here, it is reasoned that the changes in η are the slowest changes compared to the other intracrystalline processes.

In a mild-mode approximation, the change in η over time is described by an equation which, as also its solution, is known from the literature:

$$m \frac{d^2\eta}{dt^2} + \gamma \frac{d\eta}{dt} + \frac{\partial\Phi}{\partial\eta} = H(t), \tag{1}$$

where Φ is the specific Gibbs energy, i.e., the Gibbs energy referred to a unit volume of the crystal; $H(t)$ is a generalized force accounting for both external and random factors; γ is the resistance coefficient; m is the mass, having the order of the mass of an ion at a node of the crystalline lattice (γ and m can be considered constant with a good degree of accuracy). In the equilibrium state, $\partial\Phi/\partial\eta = 0$, so that when η deviates from the equilibrium value by the amount $\eta^* = \eta - \eta_0$ the value $\partial\Phi/\partial\eta$, as is evident from its expansion into a series in powers of $\eta - \eta_0$, will be $(\partial^2\Phi/\partial\eta^2)\eta^{*2}$. After η is replaced in Eq. (1) by $\eta_0 + \eta^*$ the equation becomes

$$m \frac{d^2\eta^*}{dt^2} + \gamma \frac{d\eta^*}{dt} + \frac{\partial^2\Phi}{\partial\eta^2}\eta^{*2} = H(t). \tag{2}$$

If the generalized force changes in accordance with a sinusoidal law, i.e., $H(t) = H_0 \exp(-i\omega t)$, then the solution of Eq. (2) is

$$\frac{H_0 \exp(-i\omega t)}{m[(\omega_0^2 - \omega^2) - i\Omega\omega]}, \tag{3}$$

where

$$\omega_0^2 = \frac{\partial^2\Phi}{\partial\eta^2}/m; \; \Omega = \frac{\gamma}{m}. \tag{4}$$

Equations (3) and (4) determine the normal vibration at the fundamental frequency ω_0 (mild mode). Here, we have the following for the mean square of fluctuations of the order parameter

$$\langle |\eta^*|^2 \rangle = \frac{\langle |H_0|^2 \rangle}{m^2 [(\omega_0^2 - \omega^2)^2 + \Omega^2\omega^2]}.$$

It is evident from this that $\langle|\eta^2|\rangle$ has a maximum at the frequency $\omega = \sqrt{\omega_0^2 - \Omega^2/2}$. The absorption coefficient $\omega Q^{-1}/2$ in the case of viscous dissipation alone is equal to $(\omega^2/2\rho c^3)(4/3\,\eta' + \zeta)$, where η', ζ are the first and second (volumetric) viscosity coefficients; ρ is the density; c is the speed of sound. The change in the order parameter near the phase-transition point is of a resonance character with the relaxation time $\tau = \gamma/(\partial^2\Phi/\partial\eta^2)$. This is easily shown if the denominator of Eq. (3) is written in the form $\gamma[1/\tau - m\omega^2/\gamma - i\omega]$. If $\omega\tau \ll 1$, as occurs in metals [2], then the term with ω^2 can be omitted. Thus

$$\eta^* = \frac{H_0 \exp(-i\omega t)}{\gamma(1/\tau - i\omega)}.$$

On the other hand, we obtain the following expression from (1) for relaxational changes in η, when the first term in the left side can be ignored and $H(t)$ can be taken equal to zero

$$\frac{d\eta}{dt} = \frac{\eta - \eta_0}{\gamma/\frac{\partial^2\Phi}{\partial\eta^2}}, \tag{5}$$

from which it follows that the relaxation time τ is actually equal to $\gamma/(\partial^2\Phi/\partial\eta^2)$. The frequencies ω_0, Ω, and $1/\tau$ in Eqs. (3) and (5) have the following significance: $\omega_0 = (\partial^2\Phi/\partial\eta^2)/m$ is the characteristic frequency of the mild mode, vanishing at the point of the second-order phase transition (in accordance with Landau's theory, $\partial^2\Phi/\partial\eta^2$ is proportional to $T' - T$, while it is proportional to $(T' - T)^{\gamma'}$ when fluctuations are taken into account; here, $\gamma' = 1.23$) and having the lowest nontrivial value for all normal vibrations at the point of the first-order phase transition; the frequency $\Omega = 2\delta$ characterizes the decay decrement δ for the mild mode; the frequency $1/\tau$ is the inverse relaxation time of the mild mode in the phase-transition region. Meanwhile, the relaxation time turns out to be infinitely large at the point of the second-order phase transition, while it is very large but not infinite at the point of the first-order transition. According to [3], relaxation processes should lead to a substantial increase in ζ without appreciably affecting η'. Meanwhile, $\zeta \sim \tau$. Thus, as can be seen from (5), internal friction should increase greatly in the region of phase transitions. Also, a singularity should exist on the internal friction curve at the frequency $\omega = \sqrt{\omega_0^2 - \Omega^2/2}$. Slip along grain boundaries makes a substantial contribution to Q^{-1} at the frequencies 10^{-10}-10^{-8} Hz, while shifting of twin boundaries and movement of interstitial atoms are important at the frequencies 10^{-5}-10^{-2} Hz.

Figure 1 shows results of measurement of internal friction in zirconium and cobalt. Also shown are results of simultaneously obtained measurements of the coefficient of linear expansion (the clear points correspond to measurements made with an increase in temperature to the phase-transition point, while the dark points correspond to the opposite change in temperature). There is a certain correlation between the coefficient of linear expansion and internal friction. This correlation is particularly evident at the phase transition point and can be seen clearly on the experimental curves.

It can be seen from Fig. 1a that internal friction in zirconium increases as the temperature approaches T'. Meanwhile, there are three maximums on the curve. The first is relatively small and flat and is located far from the phase-transition point. It is connected with one of the relaxation processes occurring inside the crystal (also manifest in thermal expansion); it is believed that this process is grain-boundary relaxation. The second, narrow maximum has the form of a peak and is near the phase-transition point (near 1100°K). It correlates well with the maximum on the curve for the coefficient of linear expansion; this "peak" may be connected with the features noted earlier for $\langle|\eta^*|^2\rangle$. The peak is followed by a large increase in Q^{-1} up to the point T'. It is appropriate to note that an intensive increase in Q^{-1} at a temperature above 1000°K was noted in the studies [4-6]. Two values of Q^{-1} were proposed in [6] for the temperatures 1100-1200°K, since the investigators were evidently unable to follow the path of the curve due to the narrowness of the peak.

The curve in Fig. 1b also shows two small maxima for cobalt up to the phase-transformation point. The first of these maxima is of the relaxational type, while the second is characterized by the presence of hysteresis (the hysteresis phenomenon is dealt with in [7-9]); the value of Q^{-1} increases sharply with the approach toward T'.

Thus, measurements of the internal friction of zirconium and cobalt revealed an increase in Q^{-1} with temperature as the first-order phase-transition point is approached. This increase in Q^{-1} is consistent with theoretical considerations.

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