LITERATURE CITED

1. G. Leibfried and V. Ludwig, Theory of Anharmonic Effects in Crystals [Russian translation], IL, Moscow (1963).
2. Zh. M. Tomilo and N. A. Prytkova, "Determination of the Debye temperature Θ_∞ and anharmonic component of the specific heat of scandium, yttrium, and lanthanum," Inzh.-Fiz. Zh., 48, No. 3, 424-427 (1985).
3. S. I. Novikova, Thermal Expansion of Solids [in Russian], Nauka, Moscow (1974).
4. G. S. Knapp and R. W. Jones, "Determination of the electron-phonon enhancement factor from specific heat data," Phys. Rev. B, 6, No. 5, 1761-1767 (1972).
5. A. Bieganski and B. Stalinski, "Heat capacity and thermodynamic functions of vanadium and vanadium hydride within the range 24 to 340°K," Bull. Acad. Polon. Sci. Ser. Sci. Chim., 9, No. 5, 367-372 (1961).
6. G. Leibfried, Microscopic Theory of Mechanical and Thermal Properties of Crystals [Russian translation], Fizmatgiz, Moscow (1963).
7. G. Grimvall, "Temperature dependent effective masses of conduction electrons," J. Phys. Chem. Sol., 29, No. 7, 1221-1225 (1968).
8. F. Heiniger, E. Bucher, and J. Muller, "Low-temperature specific heat of transition metals and alloys," Phys. Kondens. Mater., 5, 243-284 (1966).

EFFECT OF HEAT TRANSFER IN THE IMPULSE METHOD ON THE MEASUREMENT OF THERMOPHYSICAL PROPERTIES

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The paper considers the effect of heat transfer in the impulse method of measurement on the value of the maximum temperature and on the time for achieving its half-value. Taking this heat transfer effect into account increases the accuracy of measuring the thermophysical properties.

The impulse method of determining thermophysical properties using lasers [1, 2] is the most effective of all the known methods. It can be used for determining the thermophyscial properties directly in products without the preparation of special samples or setting up laboratory conditions. In this case, however, heat transfer from the free surfaces to the surroundings can have a considerable effect on the results of the measurements, and taking this into account makes possible an improvement in the accuracy of the measurements.

In the measurement of temperature conductivities under laboratory conditions, when heat exchange can be neglected, the essence of the method is as follows [2]. The interaction of a pulsed, focused laser beam with the solid surface can be regarded as the action of an instantaneous point source of heat of intensity q. In this case a temperature field of the following form is set up in a semiinfinite sample [3]:

$$T = \frac{2q}{c_p \rho (4\pi at)^{3/2}} \exp\left(-\frac{R^2}{4at}\right), \tag{1}$$

where $R^2 = x^2 + y^2 + z^2$.

If a thermocouple is placed at some distance y from the point of heat liberation, then after some time it will record a heat pulse which can be described by the dimensionless equation

$$\Theta = \mathrm{Fo}^{-3/2} \exp\left(-\frac{1}{4\mathrm{Fo}}\right), \tag{2}$$

where $\Theta = 4\pi^{3/2} y^3 c_p \rho T/q$ is the relative excess temperature.

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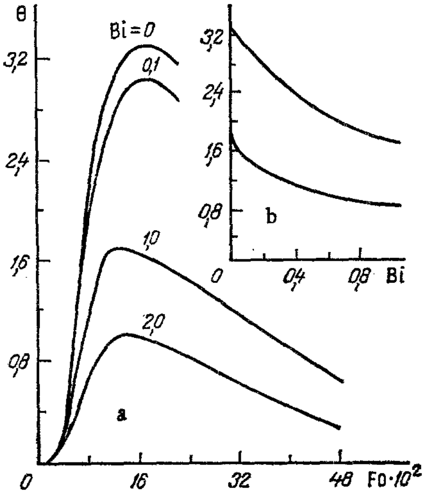

Fig. 1. Change of the relative temperatures (Θ) as a function of the dimensionless time (Fo) for various values of the Biot number (Bi) (a), and change of the relative maximum and half-maximum temperatures as a function of the dimensionless heat transfer coefficient (Bi) (b).

In the presence of heat exchange the function describing the temperature field can be represented as [4]:

$$T=\frac{2q}{c_p\rho\,(4\pi at)^{3/2}}\left\{\exp\left(-\frac{R^2}{4at}\right)-\frac{\alpha}{\lambda}\int\limits_0^\infty \exp\left(-\frac{R'^2}{4at}-\frac{\alpha}{\lambda}x'\right)dx'\right\}, \tag{3}$$

where $R'^2 = (x + x')^2 + y^2 + z^2$.

It is useful to rearrange Eq. (3) for convenience in calculations and practical applications. If it is taken into account that the heat liberation occurs at the point with coordinates (0, 0, 0) and the temperature is recorded at the point with coordinates (0, y, 0), then Eq. (3) can be rewritten as

$$T=\frac{2q}{c_p\rho\,(4\pi at)^{3/2}}\left\{\exp\left(-\frac{y^2}{4at}\right)-\frac{\alpha}{\lambda}\int\limits_0^\infty \exp\left(-\frac{y^2+x'^2}{4at}-\frac{\alpha}{\lambda}x'\right)dx'\right\}. \tag{4}$$

The integral in Eq. (4) can be represented in the form of the known function erfc U. After some rearrangements, Eq. (4) can be written in the following form:

$$T=\frac{2q}{c_p\rho\,(4\pi at)^{3/2}}\exp\left(-\frac{y^2}{4at}\right)\left(1-\frac{\alpha}{\lambda}\sqrt{\pi at}\exp\left(\frac{\alpha^2}{\lambda^2}at\right)\operatorname{erfc}\frac{\alpha}{\lambda}\sqrt{at}\right). \tag{5}$$

This expression is suitable for calculating the effect of heat exchange on the reuslt of the measurements, since it takes the form of a product of two functions, one of which describes the temperature field in the absence of heat exchange, and the other of which characterizes the heat exchange contribution. It can be seen that the effect of heat exchange can be neglected when the group $\alpha\sqrt{at}/\lambda$ is small compared to unity. This can arise when the heat exchange is small and when the time to reach a half of the maximum temperature is small, i.e., when the distance between the thermocouple and the point at which the heat liberation occurs is made as small as possible.

For quantitative evaluations and calculations it is convenient to convert Eq. (5) into dimensionless form

$$\Theta=\mathrm{Fo}^{-3/2}\exp\left(\frac{1}{4\mathrm{Fo}}\right)[1-\mathrm{Bi}\sqrt{\pi\mathrm{Fo}}\exp(\mathrm{Bi}^2\mathrm{Fo})\operatorname{erfc}(\mathrm{Bi}\sqrt{\mathrm{Fo}})]. \tag{6}$$

Figure 1 shows the dependence of the temperature on the Fourier number Fo for different values of the Biot number (Bi), as calculated from Eq. (6). This figure also shows the dependence of the maximum temperature and of the half-maximum temperature on Bi. It can be seen from the figure that for all values Bi < 0.1 the difference between the maximum tempera-

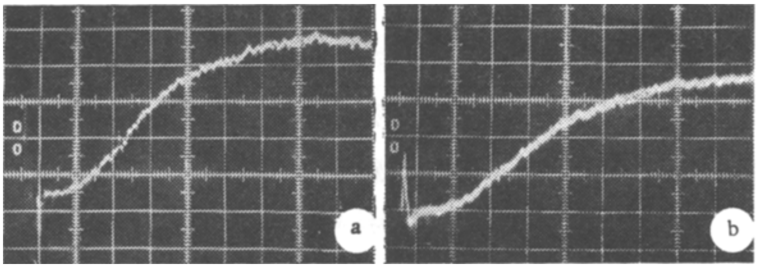

Fig. 2. Experimental dependence of the temperature on time found under vacuum (a) and open to the air (b) for 18Kh2N4VASh steel (y = 2.562 mm, T = 5°C, Bi = 0.01).

tures does not exceed 7% and the times for reaching the maximum temperature differ by no more than 0.7% compared to the calculations carried out with Bi = 0.

Figure 2 shows experimental variations of the temperature with time determined under vacuum (Fig. 2a) and open to the air (Fig. 2b). It can be seen that the maximum temperature in the presence of heat exchange with the air is lower than under vacuum by about 8%. This result corresponds to a value Bi ≈ 0.1. As before, the time for reaching the maximum temperature is practically unchanged. Thus in measuring temperature conductivities by the impulse method, it is possible to neglect heat transfer with the surrounding medium since in the determination of the temperature conductivity it is only necessary to have the value of the coordinate where the thermocouple is fixed, and the time for reaching the half-maximum temperature, which remains almost unchanged.

In measuring thermal conductivities and heat capacities it is also necessary to know the value of the maximum temperature itself, which can vary by up to 10%, depending on the experimental conditions. If the effects of heat exchange are not taken into account in this case then the error in calculating λ will also be of the order of 10%.

NOTATION

T, excess temperature; q, quantity of heat liberated instantaneously at point with coordinates (0, 0, 0); c_p, specific heat capacity; ρ, density; a, temperature conductivity; t, time; $Fo = at/y^2$, Fourier number; x', coordinate of point in negative part of x axis, directed into the depth of the object; $Bi = \alpha y/\lambda$, Biot number.

LITERATURE CITED

1. W. J. Parker, R. S. Senkins, C. P. Butler, and G. L. Abbott, "Flash method of determining thermal diffusivity, heat capacity and thermal conductivity," J. Appl. Phys., 32, No. 9, 1679-1684 (1961).
2. L. D. Zagrebin, V. E. Zinov'ev, and V. A. Sipailov, "Measurement of the temperature conductivity of massive samples by the impulse method," Inzh.-Fiz. Zh., 35, No. 3, 450-454 (1978).
3. H. S. Carslaw and J. C. Jaeger, Conduction of Heat in Solids, 2nd edn., Clarendon, Oxford (1959).
4. V. A. Sipailov, Thermal Processes in the Polishing and Quality Control of Surfaces [in Russian], Mashinostroenie, Moscow (1978).