3. A. V. Arutyunov and L. P. Filippov, Teplofiz. Vys. Temp., 8, No. 5 (1970).
4. L. P. Filippov and R. P. Yurchak, Inzh.-Fiz. Zh., 21, No. 3 (1971).
5. L. P. Filippov, Measurement of Thermal Properties of Solid and Liquid Metals at High Temperatures [in Russian], Izd. MGU, Moscow (1967).
6. L. N. Trukhanova, Author's Abstract of Candidate's Dissertation, Moscow State University (1970).
7. A. E. Sheindlin (editor), Emissive Properties of Solid Materials. Handbook [in Russian], Izd. Énergiya, Moscow (1974).

THERMAL CONDUCTIVITY AND ELECTRICAL RESISTIVITY OF NiTi IN THE TEMPERATURE INTERVAL 90-450°K

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Results of measurements of the thermal conductivity and the electrical resistivity of the metallide NiTi are reported.

The aim of the work reported here was to determine experimentally the thermal conductivity and the electrical resistivity of the metallide compound NiTi, which possesses the property of being able to "remember its shape."

The "shape-memory effect" is based on a martensitic transition and is expressed in the ability of a sample of this compound deformed at a temperature below the transition temperature T_{tr} to completely recover its shape after it is heated above T_{tr} [1-5].

According to most papers on the subject, the metallic NiTi possesses a complex crystal structure that varies depending on temperature. At a temperature of around 650°C an ordering of the structure of the high-temperature phase occurs, and below this temperature the compound has an ordered structure of CsCl type. The ordering of the high-temperature phase is accompanied by a reduction in the electrical resistivity [6]. At 60-120°C a martensitic-type phase transition occurs as a result of which the lattice of the metallide readjusts to form a more complex structure, a consequence of which is the appearance of hysteresis in the temperature dependences of the properties of NiTi. The temperature of the martensitic transition of NiTi, and so also the temperature at which shape recovery occurs, is essentially dependent on the chemical composition of the compound [3].

The properties of the metallide NiTi (51.5 at. % Ni) were measured using samples of length 80 mm and diameter 8 mm containing impurities (weight %): Co—0.19; Al—0.05; Fe—0.09; Cr ≤ 0.01; C—0.057; Si—0.09; S—0.01; Mn ≤ 0.01. The density of the material of the samples at 22°C was 6.51 g/cm^3.

The thermal conductivity was measured using an apparatus designed on the basis of the method of steady longitudinal heat flow [7]. A feature of the apparatus is the presence of a screen with an independent heater

TABLE 1. Thermal Conductivity and Electrical Resistivity of the Metallide NiTi

T, °K	90	100	150	200	250	300	350	400	450
λ, W/m·deg	10,5	12,0	16,5	18,5	18,7	18,3	—	—	—
ρ, μΩ·m	—	—	0,490	0,567	0,643	0,715	0,760	0,775	0,795

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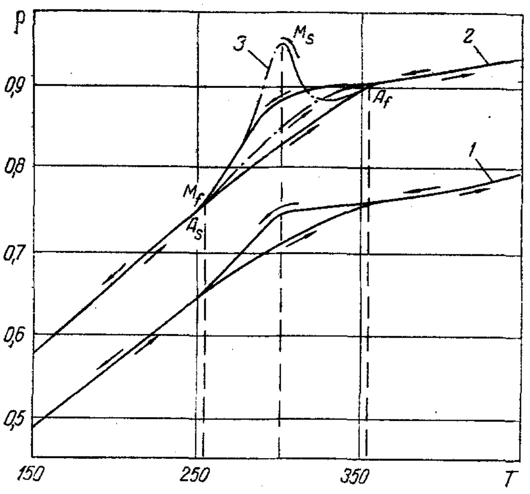

Fig. 1

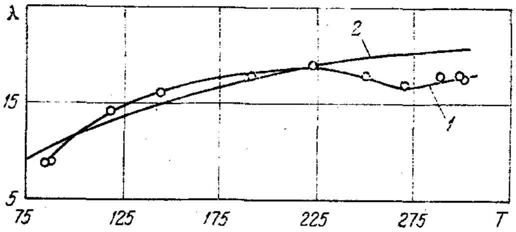

Fig. 2

Fig. 1. Temperature dependence of electrical resistivity of NiTi alloy: 1) after 30 min annealing at 1000°C and cooling with furnace; 2) 30 min annealing at 1000°C but with rapid cooling; 3) repeated cooling and heating. ρ in $\mu\Omega \cdot$ m; T in °K.

Fig. 2. Temperature dependence of thermal conductivity of NiTi alloy: 1) our results; 2) Goff's results [8]. λ in W/m · deg; T in °K.

which maintains, with the aid of a differential thermocouple and a corresponding automatic system, identical the temperature level and the temperature field on the screen and the sample, which reduces heat losses to a minimum. The sample and the screen are cooled independently of the cryostat by a separate supply of liquid nitrogen. The rate of cooling and heating of the sample could thus be considerably increased and the sample temperature level regulated with great sensitivity. The temperature of the sample was measured by three special calibrated Chromel–Alumel thermocouples with thermoelectrodes of diameter 0.2 mm. The thermal conductivity was calculated via three temperature drops and its average value then computed.

The electrical resistivity was measured on a special setup under conditions of continuous heating and cooling at a rate of around 3 deg/min. The measured quantities were recorded using a KSP-4 self-balancing potentiometer.

In the thermal conductivity and electrical resistivity experiments the geometrical factor $\Gamma = S/l$ (where S is the cross-sectional area of the sample; l is the distance between the junctions of the thermocouples) of the working part was calculated indirectly through the measured value of the electrical resistivity of the sample at 20°C.

The smoothed values of the obtained experimental data are given in Table 1. The maximum (corresponding to a confidence level of 0.95) random measurement error was 2.8% for λ and 1% for ρ; the systematic error was, respectively, 0.7 and 0.5%.

The data cited in the table characterize the properties of the alloy as it is heated up after 30-min annealing at 1000°C and slow cooling with the furnace.

Heating and cooling the samples in the interval 90-450°K are accompanied by a hysteresis in the properties of the compound, a feature which is well illustrated by the temperature dependence of the electrical resistivity (Fig. 1). Temperature cycling in the interval 150-450°K leads to the appearance of a peak on the curve of $\rho = f(T)$ taken as the sample is cooled. Maximum ρ occurs at a temperature of 305°K.

It should be noted that hysteresis is also observed on the temperature plots of other properties of NiTi, e.g., the Hall constant, the magnetic susceptibility, the velocity of sound, the specific heat [1], and also the coefficient of linear expansion [3].

Investigations showed that the character of the temperature dependence of the electrical resistivity of samples rapidly cooled from 1000°C is unchanged, although its absolute value increases sharply (Fig. 1). This sort of behavior of the electrical resistivity of NiTi is probably due to conservation of the high-temperature disordered phase in the quenching process.

The following temperature points can be distinguished on the resistivity curve of the alloy $\rho = f(T)$: $M_s = 305°K$; $M_f = 255°K$; $A_s = 255°K$; $A_f = 355°K$, which correspond to the temperature intervals of the martensitic transition in cooling (M_s and M_f — forward transition) and in heating (A_s and A_f — reverse transition). These temperature intervals of the forward and reverse transitions in the investigated alloy are close to the intervals of the transition in titanium mononickelide (51 at. % Ni) [1].

Figure 2 shows the measured thermal conductivity of the investigated alloy in the temperature interval 90-300°K. It can be seen that the thermal conductivity of the alloy increases with temperature, although above 220-230°K it decreases noticeably, and with increasing temperature a shallow minimum is observed on the plot of $\lambda = f(T)$ at 265°K.

Our results on the thermal conductivity of NiTi are in good agreement with Goff's data [8] (within the limits of experimental error) at temperatures below 230°K. The results diverge at higher temperatures. Thus, according to the data of [8], the thermal conductivity λ of NiTi above 230°K is somewhat greater than the thermal conductivity of the alloy investigated by us and monotonically increases with increasing temperature in the range 3-300°K.

The discrepancy between our results and the results of [8] lies outside the limits of experimental error and is probably connected with the effect of the structural changes that the lattice of the investigated alloy undergoes as a result of the martensitic transition in the temperature range 230-350°K; Goff, on the other hand, studied an NiTi intermetallide of stoichiometric composition, the transition in which is observed at higher temperatures (around 350-400°K) [3].

LITERATURE CITED

1. F. E. Wang, B. F. Desavage, W. J. Buehler, and W. R. Hosler, J. Appl. Phys., 39, No. 5, 2166 (1968).
2. E. V. Kachur, O. K. Belousov, and I. I. Kornikov, Dokl. Akad. Nauk SSSR, 193, No. 5, 1100 (1970).
3. I. I. Kornilov, E. V. Kachur, and O. K. Belousov, Fiz. Metal. Metalloved., 32, No. 2, 420 (1971).
4. B. A. Apaev and B. I. Voronenko, Metalloved. Term Obrab. Met., No. 1, 24 (1973).
5. R. G. De Lang and J. A. Zijderveld, J. Appl. Phys., 39, No. 5, 2195 (1968).
6. F. E. Wang, W. J. Buehler, and S. Pickart, J. Appl. Phys., 36, 3232 (1965).
7. O. A. Sergeev, Metrological Fundamentals of Thermophysical Measurements [in Russian], Izd. Standartov, Moscow (1972).
8. J. F. Goff, J. Appl. Phys., 35, No. 10, 2919 (1964).

MASS TRANSFER IN THE INTERACTION OF A SINTERED COMPOSITE WITH A LIQUID METAL

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An equation is derived to describe the migration of a liquid in a sintered composite consisting of a refractory skeleton and a bonding metal; an approximate solution is given.

Sintered composites are used in various branches of engineering, particularly ones consisting of refractory particles cemented by metal; it has been found [1, 2] that such a material absorbs molten metal rapidly if the temperature is such as to allow a liquid phase to exist. This process is used in the manufacture of components with a variety of physicomechanical properties [3]. Various technological problems involve a knowledge of the distribution of the bonding metal in the material together with the migration kinetics of the liquid. The liquid-metal uptake may be represented as a directional flow along channels formed by the

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