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EFFECTS OF HEAT TREATMENT ON THE PHONON THERMAL CONDUCTIVITY COMPONENT FOR KHROVANGAL ALLOY

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A study has been made of the effects of alloying elements in Khrovangal nickel alloy on the phonon component of the thermal conductivity in heat-treated specimens.

A promising method of reducing the overall thermal conductivity of a nickel-base alloy is [1] appropriate heat treatment. We have examined the effects of heat treatment (tempering and ageing) on the phonon component. We used khrovangal alloy, which is a standard material with thermal conductivity 9.1 W/m·K at 300°K.

We examined 18 alloys containing alloying elements at the following levels in mass %: Cr 5-15, V 5-12, Mo 4-5, W 0-4, Re 0-5, Ga 5-12, Ge 0-3 [2]. From each alloy we made three specimens of diameter 15 mm and height 10 mm and one rod of length 100 mm and of the same diameter. The alloys were quenched from 1373°K and were then aged at 823°K for 5 h.

The thermal conductivities were measured with an ITÉM-1M apparatus, while the resistivity of the rods was measured by a potentiometric method.

The measured resistivities were used to calculate the electron component of the thermal conductivity λ_e from the Wiedmann–Franz law. The phonon component λ_p was derived by subtracting the electron component from the total conductivity λ. For nine alloys, λ_p was increased after ageing, while eight it was reduced, and in one λ_p remained virtually at the same level. We determined the change in λ_p due to aging $\Delta\lambda_p = \lambda_{pt} - \lambda_{pht}$ for all the alloys. The values were used to find the parameters in the linear dependence of $\Delta\lambda_p$ on alloying-element content. A computer was used to perform the regression and variance analyses [3]. The equation takes the form

$$\Delta\lambda_p = -11.78 + 2{,}3\,(\%\ \mathrm{Mo}) + 1.57\,(\%\ \mathrm{W}) - 1.24\,(\%\ \mathrm{Re}).$$

Therefore, rhenium increases λ_p after aging, while molybdenum and tungsten reduce it.

In a nickel alloy, aging after tempering or cold deformation leads to ordering of a special kind. The corresponding structural state is known by a special term: the K state and is characterized by elevated resistivity, lattice compression, and increased elastic modulus [4]. The latter indicates that the atomic binding forces are increased.

There is at present no theory relating the thermal conductivity of these alloys to solid-solution structure. In [5], there is a detailed consideration of λ_p for low alloys. The changes are dependent in the main on the ratio of the atomic radii for the matrix and minor component, as well as on the atomic masses, concentration, and stress factor. If we assume that these factors also influence λ_p for high alloys, then tungsten and rhenium should have approximately identical effects on λ_p (with allowance for concentration) because they have very similar masses and atomic radii (183.85 and 186.2 as masses and 1.549 Å and 1.520 Å as radii correspondingly), so they should produce identical changes in λ_p in the K state, where there is lattice compression. However, these elements have opposite effects on λ_p after aging. One can explain this only by incorporating the changes in the binding forces and the lattice distortion.

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The equations derived by regression apply only for the region in which they are determined. Therefore, we refer the equation to the zero point, at which the contents of the nonsignificant elements correspond to the mean levels, i.e., Cr 10; V 8.5; Ga 8.5; Ge 1.5, while the contents of the significant elements correspond to the lower limits. The reduced contents for tungsten and rhenium coincide with the actual ones, since the minimal contents of these elements in these alloys were zero. The molybdenum contents in the alloys varied from 4 to 6%, so the reduced content is $(\%\overline{\mathrm{Mo}}) = (\%\mathrm{Mo}) - 4\%$. Then the equation is

$$\Delta\lambda_p = -2.58 + 2.3(\%\,\overline{\mathrm{Mo}}) + 1.57(\%\overline{\mathrm{W}}) - 1.24(\%\overline{\mathrm{Re}}).$$

The constant term in this equation is negative, i.e., λ_p for the zero alloy is raised after annealing, and by a substantial amount. This is due to submicroscopic regions with short-range order of Ni_3Ga type, where some of the Ga atoms are replaced by other alloying elements. There are increases in bond strength and in the proportion of covalent component due to these regions, which raise λ_p after annealing. Tungsten and molybdenum have metallic bonds and reduce the total proportion of covalent bonding and so reduce λ_p. The electron shell in Re is aspheric, so there is a certain proportion of covalent character in the Re bonds. The effects of Re when the K state arises are increased because it has an electronegativity high relative to that of nickel.

NOTATION

λ, thermal conductivity, W/m·K; λ_p, phonon thermal conductivity component, W/m·K; λ_{pt}, phonon thermal conductivity component after tempering and aging, W/m·K; $\Delta\lambda_{p\,ht}$, variation in phonon thermal conductivity component due to heat treatment, W/m·K; λ_e, electron thermal conductivity component, W/m·K; $\overline{\mathrm{Mo}}$, $\overline{\mathrm{W}}$, $\overline{\mathrm{Re}}$, reduced contents of molybdenum, tungsten, and rhenium, respectively, %.

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COMBINED SOLUTION OF THE PROBLEM OF EXTERNAL HEAT TRANSFER AND HEAT TRANSFER INSIDE A GAS RADIATION TUBE FOR THERMAL FURNACES WITH A PROTECTIVE ATMOSPHERE

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A general mathematical model of external heat transfer and heat transfer inside radiation tubes for furnaces with protective atmospheres (conjugate problem) is developed. An algorithm for solving the conjugate problem is developed.

In engineering practice, broad use is made of thermal units which include two working volumes separated by a wall: in the first, external heat-transfer processes occur; the second, as a rule, is in the form of a cylinder, in which there occurs the motion of dusty gases (metallic recuperators), petroleum products (tubular furnaces of the petroleum and

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