PHYSICAL PROPERTIES OF HOT-PRESSED TUNGSTEN–COPPER PSEUDO ALLOYS

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The results obtained in investigating the thermal and electrical conductivities and the thermal expansion in the 300-2200°K range of the hot-pressed W + (8-9)%Cu pseudo alloy are described. The effect of copper on the physical properties of the composition is discussed.

Hot-pressed tungsten–copper pseudo alloys are used as structural materials for operation at high temperatures. Their thermophysical and heat characteristics must be known in order to use them correctly under various operating conditions and perform engineering calculations of parts and units made of these materials.

We are concerned with the investigation of a number of physical properties of these materials in a wide range of temperatures: thermal conductivity in the 370-2200°K range, electrical conductivity in the 300-1970°K range, and thermal expansion in the ranges from 300-870° and from 1370-2200°K.

In investigating the strength characteristics of hot-pressed pseudo alloys, it has been found that alloys whose tungsten matrix has a relative density of not less than 0.78-0.82 display sufficiently great strength and plasticity. In connection with this, the investigations were performed on specimens having the above matrix density and containing 8-9% by weight copper. The porosity of the specimens amounted to 3-4%.

Two methods were used for measuring the thermal conductivity: the Kohlrausch method [2-3], modified to a certain extent to allow for the specific features of the material, was used in the range to 1300°K, which made it possible to increase the experimental accuracy to 4%; the method of steady-state radiant heat flux [4] was used at temperatures above 1300°K.

In the first case, a rod specimen with a diameter of 5 mm and a length of 100 mm was heated by transmitting a current through it. The heat loss through its side surface was eliminated by means of a heated tubular screen, so that heat was removed only through its end-faces.

The temperature was measured by means of platinum–platinorhodium thermocouples with a diameter of 0.2 mm. The investigations were performed in vacuum of 10^{-4} mm Hg. The electrical conductivity was measured at the same time as the thermal conductivity.

The thermal conductivity at temperatures above 1300°K was determined by means of ring-shaped specimens with diameters of 40/14 mm and a width of 30 mm. A tungsten rod heater with a diameter of 10 mm and a length of 350 mm, heated by industrial-frequency alternating current, was placed inside the specimens. The specimens were positioned in the isothermic zone and accurately centered with respect to the heater. This ensured a uniform thermal flux in the radial direction of the specimen.

A column of five rings was assembled in order to eliminate the heat loss through the end-faces of the specimen. The measurements were performed on the middle ring (Fig. 1). As a result of this experimental arrangement, there was no axial temperature gradient in the test zone of the specimen under investigation. Before starting the measurements, we checked the temperature constancy along each test specimen by means of a pyrometer after it was heated to 1300-1400°K.

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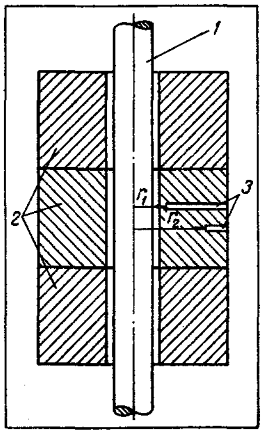

Fig. 1. Arrangement of the heater and the specimen in measuring the thermal conductivity at temperatures above 1300°K. 1) Tungsten rod heater; 2) specimens; 3) holes for pyrometric measurements.

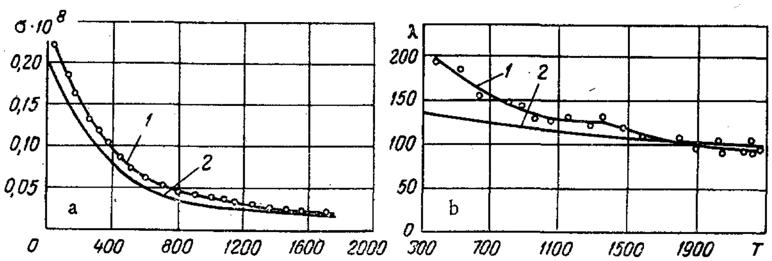

Fig. 2. Electrical conductivity $\sigma \cdot 10^8$, $\Omega^{-1} \cdot m^{-1}$ (a) and thermal conductivity λ, W/m · deg (b) as functions of the temperature (T, °K). 1) Hot-pressed W + (8-9)%Cu; 2) solid tungsten.

Two holes were drilled to different depths in the isothermic zone of the specimen for determining the temperature drop along its radius. A high-accuracy OMP-054 optical micropyrometer was used. The accuracy in determining the thermal conductivity at temperature above 1300°K was equal to 15%. The investigations were performed in a vacuum of 10^{-3} mm Hg.

At temperatures above 1300°K, the electrical conductivity was measured by using the two-probe method on cylindrical specimens with a diameter of 10 mm and a length of 120 mm. The potentiometric probes were located in the specimen's isothermic zone. The accuracy in determining the electrical resistivity was not worse than 4%. The high-temperature measurements were performed on four to five speciments. Figure 2 shows the temperature dependences of the thermal and electrical conductivities of the investigated hot-pressed tungsten–copper pseudo alloy, compensated for the specimen's porosity. The measurement results for the 370-1300°K and 1300-2200°K ranges obtained by means of the two methods are in good agreement with each other. At temperatures close to 1300°K, the measured values are virtually identical. For comparison, Fig. 2 also shows the values of σ and λ for solid tungsten borrowed from [5].

It is evident from the figures that the thermal and electrical conductivities of tungsten–copper pseudo alloys are higher than those of tungsten. The higher conductivity of the pseudo alloys is due to the effect of copper, whose σ and λ values in the solid state exceed those of tungsten by a factor of 2.5-3. The monotonic decrease of the conductivity in the range of 1320°K or 1330°K is due to the decay of these characteristics in both copper and tungsten.

The sharper reduction in the thermal and electrical conductivities of pseudo alloys at temperatures above the melting point of copper is caused partially by a reduction in the conductivity of melting copper, but probably for the most part by the outflow or evaporation of copper from pores of the tungsten matrix.

It should be noted that intensive oozing and evaporation of copper from the specimens is observed at temperatures above the melting point of copper, especially at 1700-2200°K. Analysis shows that the copper content in specimens after high-temperature investigations is less than 2-3%.

The coefficient of thermal expansion (CTE) of tungsten–copper composition in the temperature range from 300 to 870°K was investigated by means of a Chevenard quartz dilatometer during the cooling as well as the heating. The dilatometric curves are almost linear in the 300-870°K range.

TABLE 1. Coefficient of Thermal Expansion of the Hot-Pressed W + (8-9)% Cu Pseudo Alloy as a Function of Temperature

T, °K	$\alpha \cdot 10^6 \cdot deg^{-1}$	
	W+(8—9) % Cu	W from [7]
300—870	6,9	4,8
300—1370	8,2	5,3
300—2200	7,5	6,5

At temperatures from 1300 to 2200°K, the CTE of this material was determined by means of the device described in [6] and cylindrical graphite heaters, inside which the specimens were placed. The temperature along the specimen's length was kept constant. The variation of the specimen's length during heating was monitored through longitudinal slots in the heater by means of a KM-4 cathetometer with respect to the end-faces of the specimen, which were carefully machined for this purpose. The temperature of the specimen was determined by means of an optical micropyrometer with respect to the ideal blackbody model through a hole with a depth-to-diameter ratio of 3, which was drilled in the side of the specimen. The accuracy in measuring the CTE was 4-5%.

The measurements were performed in a vacuum of 10^{-3} mm Hg. The data given in Table 1 for the 1370-2200°K range were obtained by averaging the measurement results for 10 specimens.

The given CTE values for the W + (8-9)% Cu composition exceed the CTE value for tungsten, which is due to the presence of a considerable amount of copper, whose thermal expansion is much larger than that of tungsten, This effect is especially noticeable near the melting point of copper, when its expansion reaches the maximum. Hence the high CTE value of W + (8-9)% Cu in the 300-1370°K range, which is equal to 8.2 10^{-6} deg^{-1}. With continued heating beyond the melting point of copper, the latter evaporates intensively from the specimens, whose copper content diminishes. At temperatures of the order of 2200°K, the effect of copper on the thermal expansion of the composition decreases, and the CTE value of the W + (8-9)% Cu alloy approaches the CTE of tungsten.

NOTATION

σ denotes the electrical conductivity;
λ is the thermal conductivity;
α is the coefficient of thermal expansion.

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