SUPERCONDUCTIVITY OF SOME ALLOYS OF THE TUNGSTEN-RHENIUM-CARBON SYSTEM

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The electrical conductivity of some hexagonal alloys of the W–Re–C system was investigated. It was found that the alloys became superconducting at a temperature T_c which varied from 1°K for pure WC up to 5°K for WC + 6 at.% Re. Further increase of the rhenium concentration reduced T_c. The critical fields and currents were measured at various temperatures.

It has been established recently that the cubic modification of WC becomes superconducting at $T \approx 10°K$.[1] The electrical properties of the hexagonal modification of WC have been investigated by several workers.[2-4] In the last two investigations[3,4] it has been shown that this compound remains normal right down to 1.28°K.

We investigated some alloys of the W–Re–C system along the WC–Re tie-line.[5] These alloys were prepared by the powder metallurgy method from tungsten monocarbide and electrolytic rhenium (RÉTU-88-59) powders with a total impurity concentration of 2×10^{-2}% (including 10^{-3}% Mo and 5×10^{-3}% Fe). Carefully mixed WC and Re powders (grain size < 50 μ) were compacted at room temperature by a pressure of 2 ton/cm² using a 7% aqueous solution of polyvinyl alcohol as a plasticizer and binder. After drying in vacuum the samples were fired at 2100°C in a TVV-4 vacuum furnace at a residual pressure of 5×10^{-5} mm Hg. The firing took 1 h and temperature was raised within 1–2 h, depending on the intensity of gas evolution. X-ray diffraction analysis showed that single firing for 3–4 h did not produce homogeneous alloys even when the concentration of Re was low. For this reason the fired samples were ground again, compacted, and fired again under the conditions just described. It was found that when this operation was repeated three times, fully homogeneous alloys were obtained which had sharp diffraction maxima in the x-ray diffraction patterns and well-resolved $K_{\alpha_1 \alpha_2}$ doublets of the Cu radiation. An x-ray phase analysis of the alloys showed that up to 8 at.% Re they were hexagonal phases based on tungsten monocarbide. Weak lines of a second phase, identified as a solid solution based on Re, were observed in an x-ray diffractometer study of alloys containing more than 8 at.% Re. The lattice periods of the investigated alloys were practically equal to the period of tungsten monocarbide but there was some tendency for the period to decrease when the concentration of Re was increased. It is worth noting here that the atomic radii of W and Re are very close (1.39 and 1.37 Å, respectively).

Chemical and spectroscopic analyses of the principal components W, Re, and C showed that the actual compositions of the alloys differed slightly from the calculated ones.

Figure 1 shows the temperature dependence of the electrical resistivity ρ of the investigated alloys. The resistivity was determined without any allowance for the porosity. The investigated samples had dimensions ≈ 2 × 2 × 10 mm.

It was established that the hexagonal modification of WC became superconducting at T = 1.1–1°K. The superconducting transition of WC was confirmed by measurements of the magnetic susceptibility and electrical conductivity at very low temperatures. At $T \approx 0.05°K$ the critical field H_{c2} was ≈ 50 Oe.

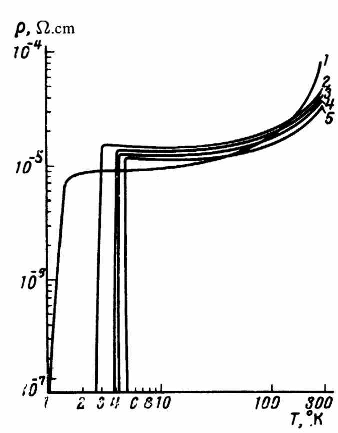

FIG. 1. Temperature dependence of the resistivity of alloys of the W–Re–C system. 1) WC; 2) WC + 1 at.% Re; 3) WC + 2 at.% Re; 4) WC + 4 at.% Re; 5) WC + 6 at.% Re.

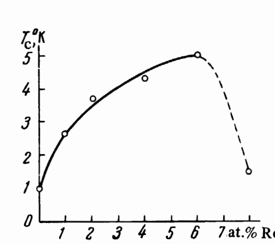

FIG. 2. Dependence of the critical temperature of the alloys on the concentration of Re.

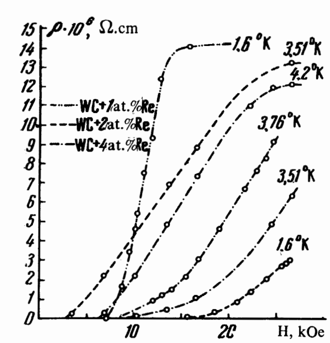

FIG. 3. Dependence of the resistivity of alloys of the W–Re–C system on a transverse magnetic field at various temperatures for a measuring current density I = 2 A/cm².

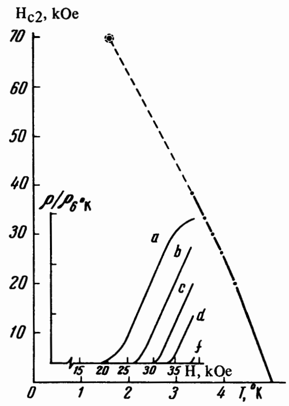

FIG. 4. Temperature dependence of the critical field H_{c2} of the WC + 6 at.% Re alloy ($I \approx 3$ A/cm^2) and the dependence of the reduced resistivity $\rho/\rho_{6°K}$ on the magnetic field intensity at various temperatures (°K): a) 4.2; b) 3.97; c) 3.77; d) 3.6; f) 3.35.

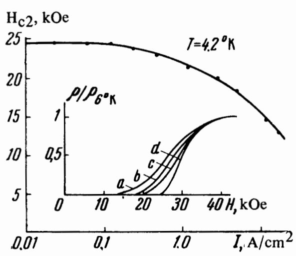

FIG. 5. Dependence of the longitudinal critical field H_{c2} on the current density I for the WC + 6 at.% Re alloy at T = 4.2°K and the dependence of the reduced resistivity $\rho/\rho_{6°K}$ on the field H for various values of the current density (A/cm^2): a) 11.7; b) 5; c) 2.7; d) 0.1.

The addition of Re increased T_c (Fig. 2). The maximum critical temperature was observed for the WC + 6 at.% Re alloy. Further increase of the concentration of Re to 8–20 at.% reduced T_c to a value close to T_c of pure Re (1.7°K).

Figure 3 shows how the superconductivity of some alloys of the investigated system was destroyed by the application of a transverse magnetic field at various temperatures using a measuring current $I \approx 2$ A/cm^2.

The electrical and magnetic properties of the compound WC + 6 at.% Re, which exhibited the maximum value of T_c, were investigated in more detail. The results, presented in Fig. 4, show the temperature dependence of the critical field H_{c2} for a measuring current density $I \approx 3$ A/cm^2. The value H_{c2} = 70 kOe at T = 1.6°K was found approximately. It was measured in a pulsed magnetic field.

Figure 5 shows the influence of the current density on the longitudinal critical field at T = 4.2°K.

The magnetic properties of WC + 6 at.% Re and WC + 2 at.% Re alloys were investigated in a homogeneous constant field by comparing the ballistic throws which were observed when the investigated samples and a standard sample of pure lead (all of the same dimensions 4 × 5 × 20 mm) were placed in turn in an induction

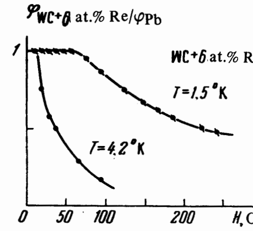

FIG. 6. Dependence of the reduced magnetic moment of the WC + 6 at.% Re alloy on the intensity of an external magnetic field at T = 1.5°K and T = 4.2°K.

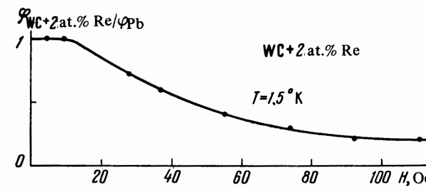

FIG. 7. Dependence of the reduced magnetic moment of the alloy WC + 2 at.% Re on the intensity of an external magnetic field at T = 1.5°K.

coil. Curves representing the ratios of the angular deflections of the ballistic galvanometer, given in Figs. 6 and 7, showed that the critical field H_{c1} for WC + 6 at.% Re was 60 Oe at T = 1.5°K and 10 Oe at T = 4.2°K; for WC + 2 at.% Re, we obtained H_{c1} = 10 Oe at T = 1.5°K.

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