TEST METHODS AND PROPERTIES OF POWDER METALLURGICAL MATERIALS

NATURE OF THE LOW-TEMPERATURE BRITTLENESS OF A W–Ni–Fe ALLOY

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The temperature range in which any constructional material can be allowed to operate is determined by its cold-brittleness temperature. It is nowadays accepted that no metal has a single, constant temperature at which it passes from the ductile to the brittle state [1]. The ductile-to-brittle transition temperature depends on a number of parameters characterizing a metal. The most important are its structure, amounts of alloying elements and uncontrolled impurities, and surface condition. In recent years it has been established that, even in single-phase polycrystalline alloys, loss of ductility occurs in two temperature ranges. This phenomenon is believed to be linked with the relative levels of properties characterizing the materials of the boundaries, regions adjoining the boundaries, and main volumes of the grains [2].

The work described below was undertaken with the aim of studying the physical nature and character of manifestation of low-temperature brittleness in a tungsten alloy produced by the powder metallurgy technique. An alloy containing 90 wt. % W, 7 wt. % Ni, and 3 wt. % Fe was chosen for investigation. Two batches of specimens were used, cooled at different rates from the temperature of sintering in the presence of a liquid phase: ~600 for one batch and ~5 deg C/min for the other.

The specimens were subjected, using a three-point arrangement, to mechanical bending tests under a static load at temperatures ranging from +20 to −196°C, during which plots of their bending deflection vs load were recorded; in addition, they were examined metallographically with a JSM-V3 scanning electron microscope. The bending test specimens – strips 1 × 4 × 40 mm in size – were either in the as-manufactured condition or additionally machined to a surface roughness Rz ≤ 32 μm. To study the process of deformation of the alloy by means of a light microscope, on each specimen, on one of the side faces parallel to the load application axis, before the test–an area was prepared for metallographic examination.

The structure of the W–Ni–Fe alloy was found to consist of round monocrystalline grains of tungsten and a binder phase – a nickel-base solid solution. In the structure of the alloy there were three types of boundary, between the phases, between binder-phase grains, and between tungsten grains (Fig. 1).

During the fractographic investigation quantitative assessments were made, on a 1-mm² fracture surface area, of the proportion of intergranular rupture along W–W boundaries (Fig. 2). Curves of the temperature dependence of mechanical properties (Figs. 3 and 4) were obtained by processing plots of specimen deflection vs load. The alloy investigated, like all metals and alloys with the body-centered cubic lattice (bcc) and many alloys based on metals with the face-centered cubic lattice (fcc) [1], is characterized by a sharp dependence of its strength characteristics on temperature. With fall in temperature its limit of proportionality σpr (Fig. 3), arbitrary yield stress (0.2% proof stress) σ0.2, and rupturing stress σr (Fig. 4) grow. The character of the variation of these properties depends on the rate of cooling of the alloy from the sintering temperature. It has already been established that decreasing the rate of cooling of this alloy leads to the decomposition of the nickel-base solid solution, which is accompanied by the precipitation of a disperse phase in the binder and at boundaries between the phases [3, 4]. It would appear that it is these structural changes that explain why heat treatment conditions affect the modulus of elasticity of the alloy, which is characterized by the σ/ε (stress/strain) ratio, and its resistance to plastic deformation and rupture. The deflection vs temperature curve of the W–Ni–Fe alloy, like those of cast Group VIa metals and their alloys [2], shows two ductility decrease ranges, arbitrarily designated Tx₁ and Tx₂ (Fig. 4).

In the temperature range below Tx₂ a partial loss of ductility is observed; before rupture specimens experience appreciable plastic deformation. A study of the plastic bending strain of the alloy under a light microscope revealed that the first slip bands appear in the ductile binder phase. Increasing the load causes...
Fig. 1. Microstructure of W–Ni–Fe alloy, ×900. Types of boundary observed: 1) between W and Ni phases; 2) between W grains; 3) between binder-phase grains.

Fig. 2. Diagrammatic representation of surface of W–W boundary adopted as unit of measurement in quantitative microfractographic analysis of alloy.

Fig. 3. Effect of temperature on limit of proportionality of W–Ni–Fe alloy: 1) slow cooling (v ≤ 5 deg C/min); 2) rapid cooling (v ≥ 600 deg C/min).

Fig. 4. Temperature dependence of strength and ductility properties of W–Ni–Fe alloy. Fig. 4a. Effect of rate of cooling of alloy: 1) slow cooling, v ≤ 5 deg C/min; 2) rapid cooling, v ≥ 600 deg C/min. Fig. 4b. Effect of machining of surface: 1) unmachined surface; 2) machined surface.