STRENGTH OF DISPERSION-HARDENED MOLYBDENUM ALLOYS

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Dispersion hardening is one of the principal methods of creating P/M materials. The most promising heat-resistant dispersion-hardened alloys are based on molybdenum with aluminum nitride [1].

Mixtures of powdered molybdenum and aluminum nitride, the chemical compositions of which were given in [2], were prepared by a special mixing technique with simultaneous pulverization in a ball mill. With an original fineness of 5-10 μ, pulverizing for 50 h produces even distribution of AlN particles and reduces their size to 0.5-2 μ. Pulverizing for 70 h leads to evenly distributed particles with a size of 0.5-1 μ.

We tested molybdenum and its alloys with 2, 4, and 8 vol. % AlN. The molybdenum alloys with AlN were produced by hot extrusion or activated sintering.

To determine the effect of the particle size and the quantity of particles on the strength of molybdenum, we investigated the temperature dependence of the hardness with additions of 4 and 8 vol. % AlN with particle sizes of 0.5-2 μ and 0.5-1 μ. The samples were obtained by hot extrusion at 1800 °C under a pressure of 260 kg/cm² with holding under load for 5-7 min. To prevent carburizing, the inner walls of the graphite molds were coated with an emulsion of powdered molybdenum, and after hot extrusion the samples were thoroughly cleaned, with removal of the outer carburized layer (the maximum carbon content did not exceed 0.09%). The density of the samples was 95-98%.

The strength was determined on samples prepared by hot extrusion and activated sintering. In this case the hot-extrusion conditions differed substantially from those indicated above. Compacts weighing 2 kg were obtained in a 100-ton press at 1700 °C under a pressure of 130 kg/cm², with holding for 20 min. The density of the samples did not exceed 88-94%. Activated sintering of the samples consisted of adding 0.5 vol. % carbonyl nickel during mixing. After mixing, the powders were extruded in rods and sintered at 1500 °C in a vacuum (10⁻⁴ mm Hg) for 1 h, with heating at 250 deg/h. The density of the samples was 93-98%. After activated sintering or hot extrusion, the rods were rolled at 900-1000 °C in a vacuum with 80% deformation.* Samples were prepared from the rods and rolled bands by spark machining for tensile tests at 20 °C and long-term strength tests at 1100 °C in an atmosphere of purified argon, using the equipment described in [3-5]. The hardness was measured in the UVT-2 apparatus [6]. For this purpose the samples were treated in a flat surfacing machine with a diamond disk after hot extrusion, and annealed at 1500 °C for 1 h, after which microsections were prepared.

As can be seen from Fig. 1, the hardness of molybdenum decreases with increasing temperatures. In the range of 200-300 °C the hardness drops from 178 to 80 kg/mm². At temperatures from 300 to 900 °C the hardness decreases at a lower rate, dropping from 80 to 56 kg/mm². At higher temperatures the hardness decreases at a higher rate — from 56 kg/mm² at 900 °C to 18 kg/mm² at 1500 °C. The addition of AlN does not change the character of the variation in hardness with temperature, although the hardness of alloys with AlN is higher than that of molybdenum alone at all temperatures tested. The hardness of the alloy

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Fig. 1. Variation of hardness with temperature. 1) Mo; 2) Mo + vol. % AlN (0.5-2 μ); 3) Mo + 8 vol. % AlN (0.5-2 μ); 4) Mo + 4 vol. % AlN (0.5-1 μ).

Fig. 2. Load-extension diagram for Mo and its alloys.

Fig. 3. Microstructure (500 x) of Mo + 2 vol. % AlN. a) After hot extrusion; b) after rolling.

with AlN particles 0.5-1 μ in size is higher than that of the alloy with the same composition but particles 0.5-2 μ in size: The hardness of the alloy with particles of AlN 0.5-1 μ in size at 800 °C is 160 kg/mm², while with particles 0.5-2 μ in size it is 120 kg/mm².

The results obtained indicate that the dispersity of the AlN particles affects the hardness of the molybdenum matrix — the finer the particles, the higher the hardness of the alloy. Refining of the particles plays a more notable role in increasing the hardness than the addition of larger amounts of AlN. The hardness of the alloy with 4 vol. % AlN with a particle size of 0.5-2 μ is 142 kg/mm² at 400 °C. When the AlN concentration is raised to 8 vol. % the hardness increases to 158 kg/mm², but when the particle size is reduced to 0.5-1 μ the hardness increases to 200 kg/mm² for the alloy with 4 vol. % AlN.

The strength tests of hot extruded molybdenum showed that the ultimate strength does not exceed 35-40 kg/mm², with low elongation (1-2%). A substantial increase in the resistance to fracture is observed with the addition of 2 and 4 vol. % AlN. The ultimate strength of the alloy with 2 vol. % AlN reaches 75-80 kg/mm², and the yield strength 70-73 kg/mm², with relatively high elongation (averaging 12-14%). The alloy with 4 vol. % AlN has a higher strength than the alloy with 2 vol. % AlN; its ultimate strength is more than double (97-100 kg/mm²) that of hot extruded molybdenum. Figure 2 shows typical load-extension diagrams for hot extruded molybdenum and the alloys with 2 and 4 vol. % AlN. The results of the strength tests and the values of the hardness obtained for molybdenum and its alloys with AlN are given in Table 1.

Only the hot extruded rods with 2 vol.% AlN were subjected to rolling. Due to its brittleness and low strength, hot extruded molybdenum cannot be rolled. The alloy of molybdenum with 2 vol. % AlN has a high hardness (as high as 360 kg/mm²) and strength (σ_b = 124 kg/mm²) after hot extrusion and rolling. The characteristic feature of this alloy is its high ductility after annealing of the rolled strip. After annealing at 1200 °C for 1 h the elongation rises to 35%, the ultimate strength and yield strength remaining high.

After hot extrusion, the alloy with 2 vol.% AlN has an even grain size with evenly distributed particles (Fig. 3a). After rolling, the grains become elongated in the rolling direction (Fig. 3b), acquiring the typical texture of rolled metal.