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Investigation of Effect of Surface Decarburization on Mechanical Properties of Molybdenum Using Multifractal Formalism

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ABSTRACT

The effect of surface decarburization (by annealing in a vacuum at 800°-1500°C) on the mechanical properties, fracture mechanisms and changes of multifractal characteristics of fracture surfaces of Mo wires 1 mm in diameter under static tensile loading was investigated. It was shown that decarburization influences the self-organization of the dissipative structures in the near wire surface layers. The resulting homogenization of the defect structures and decrease in defect localization improve the mechanical properties of the specimens. For example, it is possible to increase the toughness and plasticity by 9% and 55%, respectively. An efficiency of multifractal parametrization of material structures is demonstrated.

INTRODUCTION

As is known, a material subject to deformation represents an open thermodynamic system, and its mechanical properties are controlled by the dissipative structures evolving during the energy, substance and information exchange of the system with the environment (Ivanova et al., 1994; Prigogine, 1980). As to molybdenum, evolution of such structures (in the number of dislocation, sub-grain, grain, etc.) in the near surface layers of the relative depth 0.005-0.008 is somewhat of a factor as compared to the internal volumes of material, the relative depth of the zone with the most intensive changes in material structure being approximately 0.0008-0.002 (Kramer, 1986; Kolmakov et al., 1995). That is why the state and behaviour of near surface layers influence the mechanical properties of the material on the whole. From a general point of view, the self-similarity of the resulting material structure cannot be described on the basis of the concept of geometrical self-similarity only (Mandelbrot, 1983), and multifractal description is more adequate (Mandelbrot, 1983; Halsey et al., 1986).

An appearance of the techniques of digital multifractal parametrization of structures made the first steps in this direction possible (Kolmakov et al., 1995; Vstovsky et al., 1993, 1994, 1995).

The mechanical properties of Mo depend strongly on the presence of carbon and nitrogen. In particular, decrease in carbon contents results in significant increase in plasticity indexes. In this regard, it is interesting to use the surface decarburization to improve the mechanical properties of Mo and its alloys.

In this work, the effect of surface decarburization (by annealing in a vacuum at 800°-1500°C) on the fracture processes, features and mechanical properties of Mo wires 1 mm in diameter under tensile loading was investigated using the technique of multifractal parametrization of structures.

MATERIALS AND TESTS

The wires 1 mm in diameter of commercially pure Mo (0.025C, 0.005N, 0.16Ti) with electropolished surfaces were annealed in a vacuum of 10^{-3} Pa at different temperatures (800°, 1400° and 1500°C) for 2 h.

The tension tests were carried out by the universal test machine INSTRON TT-DM with a cross-head speed of 1 mm/min. The fractographic investigations were carried out using an electron-scanning microscope JSM-U3. The decarburized layers of the specimens were removed by electropolishing after annealing and tested for comparison.

Carbon contents in the near surface layers of wires were determined by the XPS-method using the Leybold AG LHS-10 device. Three types of specimens were investigated after annealing at 1400°C: 1) with a decarburized layer, 2) with removed (by electropolishing) decarburized layer of the depth of 20-23 μm, and 3) with a carbon layer on the surface which formed during the annealing.

The latter was used for additional control of reliability of the results obtained. A decrease in carbon and Mo_2C contents in the near surface layer was obtained for specimen type 1 and an increase in their contents for specimen type 3 as compared to type 2. An overall depth of intensive diffusion processes was evaluated by specimens of type 3 and was found to be 0.7-0.9 μm (the relative depth h/d = 0.0007-0.0009). For specimen 1 at the depth 0.5±0.1 μm the relative carbon content was 0.94 in comparison with a specimen of type 2.

To characterize quantitatively the self-organization of dissipative structures in the near surface layers of Mo wires under tensile loading, the special technique of multifractal parametrization was used as applied to fracture surfaces (Kolmakov et al., 1995; Vstovsky et al., 1993, 1994, 1995); this was elaborated on the basis of original information-theoretic interpretation of multifractal formalism (Vstovsky et al., 1994, 1995). The method offers two quantitative characteristics: of structure uniformity f_{40} and hidden orderness $\Delta_{40} = D_1 - D_{40}$, that are to be evaluations of f_∞ and Δ_∞, respectively (see below). The greater the f_{40}, the more uniform the structure; the greater the Δ_{40}, the more ordered the structure. The technique was as follows. First, the photos (128×128 mm) were digitized by partitioning them into the 64×64 boxes which were marked 1 for the places of fracture of grains and 0 for the places of intergranular fracture events. In our case the scale was 0.5 μm in 1 mm of photos, and the overall real size of the photographed zone was 64×64 μm, which corresponds to an overall depth of near surface layer with nonuniform structure. Then, these two-dimensional matrices were partitioned into larger boxes: sizes $l_k \times l_k$, l_k = 4, 6, 8, 10, 12, 16, 21, 32 with k = 1, ..., 8

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