The Open-Access Journal for the Basic Principles of Diffusion Theory, Experiment and Application

Theory of nonequilibrium grain boundaries and its applications to describe ultrafine-grained metals and alloys produced by ECAP

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The research presents key approaches to describing the features of evolution of structure and physical and mechanical properties of ultrafine-grained (UFG) metals and alloys obtained through equal channel angular pressing (ECAP).

It was shown that the specificity of UFG materials from the defect theory perspective lies in the fact that most processes controlling their behavior and properties develop not in the crystal lattice (grains) like in conventional materials but rather in grain boundaries. The main type of defects in UFG materials defining the nature of these processes are neither dislocations nor vacancies (as in conventional materials) but rather inner interfaces. The key features of grain boundary processes are determined by the interaction of grain boundaries with dislocations and point defects getting in there from the lattice.

To describe structural features and properties of UFG materials, a theory of nonequilibrium grain boundaries in metals and alloys was proposed [1, 2].

It was shown that the structure of grain boundaries could be described using the so-called 'island model'. The key parameter that characterizes the structural condition of grain boundaries is free volume. It was shown that anomalies in diffusion parameters and thermodynamic characteristics of nonequilibrium grain boundaries arise from the increase in their free volume driven by the free volume introduced by lattice dislocations that get into the grain boundaries. Expressions were obtained that describe changes in the energy of grain boundaries and their diffusion parameters during their interaction with individual dislocations and lattice dislocation flows. The dependence is determined between the grain boundary diffusion ratio and deformation rate, as well as the material structure parameters.

Based on the theory of nonequilibrium grain boundaries, processes controlled by diffusion in nonequilibrium grain boundaries were reviewed. Descriptions were provided as to the features of grain boundary diffusion, grain boundary sliding, recovery and recrystallization processes, superplasticity, features characterizing the evolution of mechanical properties in materials with nonequilibrium grain boundaries such as UFG metals and alloys obtained through ECAP.

The report pays special attention to the issue of thermal stability of mechanical properties of UFG metals and alloys. The results of experimental and theoretical studies into return and recrystallization processes during annealing of UFG metals and alloys were described.

It was shown that the structural condition of grain boundaries is one of the key factors affecting the mechanical properties of UFG metals: during ECAP, UFG materials form grain boudaries that contain enhanced density of introduced defects which create long-range inner stress fileds. This leads to anomalies in mechanical properties of UFG materials at room temperature (deviation from the Hall-Petch relation, the effect of simultaneous increase in strength and ductility, the effect of optimal grain size for superplasticity, etc.).

The research was performed with the support of the Russian Ministry of Education and Science (Project No. 11.1884.2017).

References

[1] V.N. Chvuil'deev *Non-equilibrium grain boundaries. Theory and applications*. Moscow: Fizmatlit. 2004. 304 p. (in Russian).

[2] V.M. Segal, I.J. Beyerlein, C.N. Tome, V.N. Chuvil'deev, V.I. Kopylov *Fundamentals and Engineering of Severe Plastic Deformation*. New York: Nova Science Publishers, 2010. 542 p.