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NON-EQUILIBRIUM FEATURES OF CONTINUOUS RECRYSTALLIZATION PROCESS AT SEVERE PLASTIC DEFORMATION OF COPPER

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Abstract. It is shown that separation of scalar dislocation density into two parts, giving densities of mobile and immobile dislocations, is providing a possibility to predict continuous dynamic recrystallization (DRX) process caused by severe plastic deformation of metallic materials. The proposed approach is making it possible to predict a rather extent set of material microstructure properties that can be measured experimentally, based on a minimum set of "tuning" parameters. Received predictions are verified by comparison to experimental results and predictions received using another known dislocation plasticity and dynamic recrystallization models**.**

1. Introduction

Nowadays none of the known models can offer a correct prediction of deformation that should be applied to a sample in order to receive desired defect structure with a-priori given physical properties. At the same time the available dislocation based plasticity models [1–5] are able to make a reliable prediction of resultant material grain size after one or several ECAP passes [5]. Unfortunately, these models contain several "trimming" parameters that should be evaluated experimentally. Further development of ultrafine-grained (UFG) structure material engineering requires an analysis of the existing models of SPD, a study of influence of "trimming" parameters on the received solutions, a study of the possibility to provide clear physical meaning and measurability to these parameters, a study of validity limit of these models, etc. The final result should consist in appearance of a rather universal material behaviour model having no "trimming" parameters and applicable for prediction of a wide range of processes and materials.

2. Modification of the classical model for a separate account of mobile and immobile dislocation densities

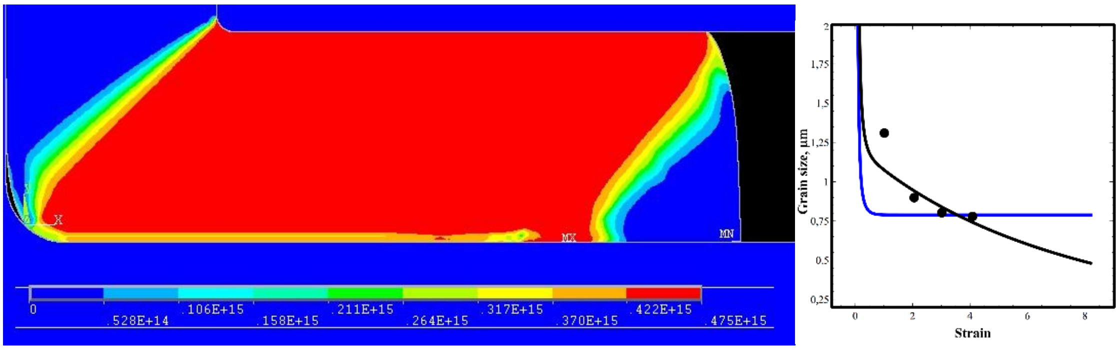
A model proposed by Mayer and co-authors [2, 3] extends the applicability limits and improves the classical model [1]. For quasistatic case it can be reduced to a classical model with the principal distinction from this model consisting in separation of dislocation density ρ_D into two parts giving densities for mobile ρ_D^{mob} and immobile ρ_D^{im} dislocations. Evolution of

$$d = \beta \rho_D^{-1/2}, \tag{2}$$

Here β is a coefficient dependent on dislocation cell geometry. It can be expected that (2) should give a mean value for a size of grain appearing in material after intensive plastic deformation. The problem is that the model (2) of recrystallization is correct for equilibrium processes, which is not true for SDP processes. This approach does not give a possibility to predict evolution of grain structure from large grains to ultrafine grains (UFG) under ECAP. Due to this reason, in [10] authors introduce a dependency for β : $\beta = \beta_\infty + (\beta_0 - \beta_\infty)\exp(-\gamma\varepsilon)$, which results in appearance of three additional fitting parameters. An alternative approach can be proposed should one suppose the degree of defect structure nonequilibrium to be an important factor controlling the process of dynamic recrystallization. In [7] volume fraction of consolidated triple junctions J was introduced, then the mean distance between the elements of stable structure will be given by $d = \beta \rho_D^{-1/2} / J$. Supposing, for simplicity, that the rate of nonequilibrium grain boundaries fraction change is proportional to the ratio between mobile to immobile dislocations, the following form of recrystallization law can be proposed [7]:

$$\begin{cases} J = p^3, \\ \dot{p} = \alpha[V_C(\rho_D^{mob} - \rho_D^0)/\rho_D^{im}], \end{cases} \tag{3}$$

where parameter p is the fraction of nonequilibrium boundaries of dislocation cells in dislocation structure. The approach is shown to be applicable to predict experimentally observed correlation between the accumulated strain and the observed resultant grain size (see Fig. 2b). The best coincidence between the studied experimental data and predictions given by (3) is achieved for α = 0.083.



(a) (b)

Fig. 2. (a) Distribution of total dislocation density and (b) DRX curve: the black line corresponds to calculation by (5) with $\beta = 2.6$. The blue line corresponds to calculation using (2) with $\beta = 21$. The circles correspond to the experimental data from [10].

4. Conclusions

It is shown that in many cases the simplest classical model can be used in order to predict a defect hardening of the deformed material. Additional features for dislocation density based models given by separation of dislocations into mobile and immobile [2, 3] make the prediction of defect structure evolution more realistic, providing a possibility to account the changes in material fine structure. New approach for DRX has been proposed. Among the advantages of this approach is the introduction of a single additional parameter (to be found from correspondence to experimental data) controlling DRX process instead of three fitting parameters introduced in another [10] known approach to the problem while the prediction accuracy is not reduced.

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