The modelling of the influence of thermoelctrical action on mechanical properties of the metals with structure of defects

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Abstract

We consider an electrodynamical action taking account of the microdefects developing in the material. We study a material consisting of periodically distributed representative elements containing defects of different type (cylindrical microvoids, plane microcracks). The main result of this study is: we have found that microdefects are close and healed when electric current is run through the material and thermal stresses localize between defects, which results in hardening of the material. Furthermore, as increased temperature localizes near the tips of microcracks, outmelting of the material takes place leading to increasing material porosity. The obtained results explain the mechanism of variation of the material properties and the effect of electrosuperplasticity.

Keywords: thermal electrosuperplasticity, direct numerical modeling, damage material, electric field temperature localization

1. Introduction

Thermal electroplasticity is a comparatively young field of the theory of plasticity. The first investigations in this field appeared only in the last few decades of the 20th century. These were mainly experimental studies related to technological processes of metal working by electric field. They showed that electric current working of blanks made of hardly-deformable metals and alloys simplifies the subsequent mechanical treatment, improves the plastic properties of the product and has advantages over the traditional methods of thermal processing. [1, 9].

This results attempted to develop by theoretical way the scientific foundations of thermal electroplasticity using both micromechanical dislocation representations [6] and macroconcepts of modern thermal electromechanics [1, 4]. But the problem turned out to be very complicated because of experimental difficulties arising in attempts to perform efficient separation of the coupled effect into individual components, purely electrical and thermomechanical [1, 9]. As a result, this field of the theory of plasticity has not yet been developed completely. So far, there is no unified opinion about the nature and physical mechanism of this process, and discussion about the fundamental hypotheses are still continued [5, 8].

Note that it was not until recently that certain advances in solving problems of coupled thermal electroplasticity were made when versatile software packages were developed for solving such problems taking into account the structure of damaged materials [3]. Also due to the tremendous progress in increasing computer power, it became possible to perform direct modeling of processes in media containing micro- and mesodefects. This gives hope for significant advances in the field of thermal electroplasticity in the near future.

In the present paper, we attempted to study the problem in more detail by direct numerical simulation and to keep track of the material structure variations after the action of electric current not only at the initial stage but also during the entire subsequent evolution, taking into account the electric field concentration at microdefects. This study has confirmed the effect of closing cut-like defects and has also shown that this does not exhaust the structure evolution – subsequently temperature localization occurs at the crack ends and voids are formed. Thus, the structure with microcracks does not transforms into a continuous material but becomes a porous material that has a lesser yield strength increasing plastic deformation of the sample as compared to the original structure. This corresponds to the experimental data of [1, 2] and explains the effect of electroplasticity in principle.

2. Statement of the problem

We consider a coupled model of action of electromagnetic field on a sample made of a preliminary damaged material. The problem is solved in two stages. At the first stage, we study the thermal electrodynamical problem in order to obtain the temperature distribution in the sample. Here, the boundary conditions are set so that electric current is applied at one of the sample ends, while the other end is kept at zero potential. Because of high rate of heating, we can assume that the process is adiabatic provided that the sample boundaries are thermally insulated. The action of steady-state electric current brings about a steady-state process of heating of an elastoplastic material with periodic distribution of microcrack-like defects. To determine the temperature field distribution in the sample, we solve a coupled thermoelectric problem of successive loading, where the loading parameter is the applied electric flux. At the second stage, we solve a coupled unsteady quasistatic thermomechanical problem of tensile deformation of the heated elastoplastic sample with finite displacements applied to its ends taking account of the initial temperature field distribution in the material obtained at the first stage.

The main goal at the second stage is to obtain the **R**(**U**) – diagram of the material, where **R** – is the reaction force and **U** – is the displacement applied. At this stage, we solve a quasistatic problem in which the magnitude of the applied displacement **U** is taken to be the parameter of the successive loading. Using direct simulation by the finite element method, we solve the problem of tensile deformation of a sample made of a porous material with periodic distribution of defects; the ends of the sample are subjected to initial displacements uniformly distributed across the sample width and an initial temperature distribution $\theta\big|_{t=0} = \theta_0(\mathbf{x})$ is given.

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The sample has a periodic structure of defects and consists of finitely many (seven) representative elements. The periodic structure is composed of representative elements each having a cylindrical or plane cut-like defect.

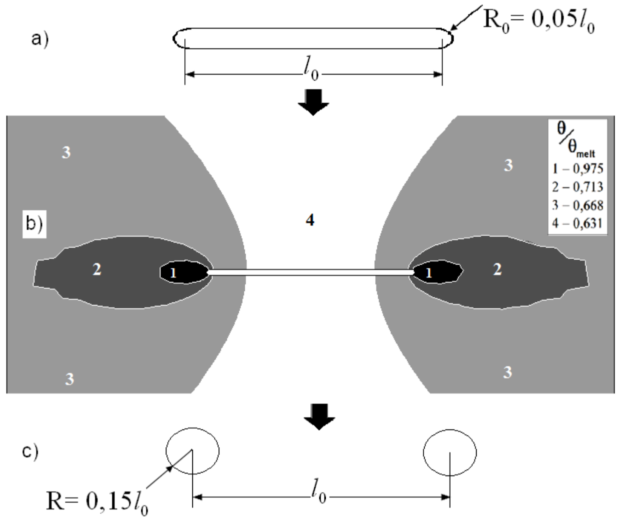

Figure 1: Evolution of defects shape after applying electric current. a) initial cutlike defect, b) θ / θ_{melt} temperature distribution, c) final shape of cylindrical pores.

3. Results

We consider a model of separate action of electromagnetic field on a sample of a preliminary damaged material with periodically located circular microvoids and microcracks. We study the problem of heat release near a microdefect in the material representative element containing a single void. At the first stage, we consider an ideally plastic material consisting of a periodic system of representative elements. The representative elements contain cut-like defects with rounded ends. It is shown that, in the presence of circular cylindrical defects and under the action of electric current, a weak temperature concentration arises, while in the case of cuts, this concentration is very significant. We investigated the temperature field and the stress-strain state localization for isolated representative elements with cut-like defects and for a sample consisting of seven periodic representative elements subjected to the same thermal electromechanical action. The temperature and stress-strain state distribution in the representative elements, both isolated and those inside the sample, are the same if the elements are not on the sample boundary. This gives hope that, in problems with a large number of representative elements, the computations can be simplified by using the periodicity condition inside the body and the symmetry condition on the boundaries of elements located on the body surface. Because of the strong temperature concentration, microdefects close and the material melting occurs at the cut ends. Thus, the ordered structure of plane cut-like defects is replaced by a structure of cylindrical defects.

At the second stage, we solve the thermomechanical problem of the sample tension with the initial temperature distribution obtained at the first stage. We determine the stress-strain state. The computations permit determining the average tensile diagram for the material with defects. The obtained results a explain the mechanism of electric superplasticity. The Fugure 2 shows the material softening after applied electric currant.

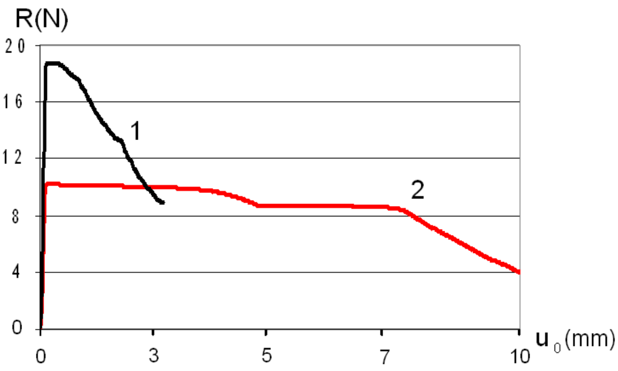

Figure 2: The average force-elongation diagram for sample before (1) and after (2) applied electric current.

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