Reduction of the number of material parameters by ANN approximation of material functions in the viscoplasticity formulation for anisotropic solids

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Abstract

In recently proposed viscoplasticity formulation for anisotropic solids (metals) one needs to identify 28 material parameters to handle particular metal behaviour in adiabatic conditions [8, 2]. In [8] it was shown that without loss of model generality one can reduce this number to 21. The paper outlines a proposition of further reduction by using ANN approximation of selected material functions. As the result, we decrease the number of material parameters to 18.

Keywords: material properties, anisotropy, viscoplasticity, ANN approximation

1. Introduction

Mathematical modelling of metals behaviour becomes more and more difficult to match recent industrial requirements (especially thermo-mechanical coupling including damage). The modelling discussed must reach micro/nano scale of observation to capture physical phenomena crucial for its proper description [3]. As result, the modern constitutive models include the high number of material parameters.

The experimental (or mathematical) identification of such models (if possible!) can be very expensive (in its common or computational time meanings). It is then obvious that the reduction of the number of material parameters, without loss of particular model generality, is advisable. To meet such needs, we present in this paper the considerations of using the artificial neural network (ANN) for material functions approximation in recently proposed viscoplasticity formulation for anisotropic solids, which finally effects in the reduction of desired material parameters (from 28 to 18).

2. Main results of viscoplasticity formulation for anisotropic solids

2.1. General discussion

The material model is stated in terms of the continuum mechanics, in the framework of the thermodynamical theory of viscoplasticity together with a phenomenological approach [7, 4, 9]. Formally, the constitutive structure belongs to the class of simple materials with fading memory, and due to its final form and the way of incorporating the fundamental variables, belongs to the materials of rate type with internal state variables [10].

The key features of the formulation (for detailed and more general formulation please see [8]) are: (i) the description is invariant with respect to any diffeomorphism (the obtained model is covariant [5]), (ii) the obtained evolution problem is well-posed, (iii) sensitivity to the rate of deformation, (iv) finite elastoviscoplastic deformations, (v) plastic non-normality, (vi) dissipation effects (anisotropic description of damage), (vii) thermomechanical couplings and (viii) length scale sensitivity.

2.2. Material parameters

Recall that the adiabatic process described in terms of the discussed model needs the identification of 28 material parameters [8]. We propose grouping them as follows:

• 6 parameters related to viscoplastic evolution (including 5 dimensionless),
• 9 parameters related to anisotropic microdamage evolution (including 8 dimensionless),
• 6 parameters shared with viscoplastic and microdamage evolution (including 4 dimensionless),
• 4 parameters related to thermal evolution (including 2 dimensionless),
• 2 elasticity parameters, and
• reference density,

with all parameters being non negative. In [8] it was shown that without loss of model generality one can reduce the number of material parameters to 21.

Next, we discuss further reduction of parameters based on ANN approximation of work hardening-softening and threshold stress for microcrack growth functions.

3. ANN approximation

We base on experimental results taken from [6]. In [6] the authors have investigated the behaviour of DH-36 steel for 3 different strain rates (0.001, 0.1 and 3000 s⁻¹) through 6 different temperatures (77, 296, 400, 500, 600 and 800 K) in compression. Notice, that results in compression do not allow for proper damage calibration in the model (damage occurs mainly due to tension in metals).

Now, let us assume that such experimental results are sufficient to cover all characteristic phenomena for phenomenological description of analysed steel (in our case for modelling of extremely fast thermomechanical processes, the range of strain rates and simultaneously temperatures should be increased - nevertheless the presented algorithm for ANN approximation remains un-
changed for larger data set). It guarantees that not only the approximation but also extrapolation from ANN will be done with acceptable errors.

We propose the following approximation:

\[ \kappa = A \xi_\kappa, \]
\[ \tau_{eq} = A \xi_{eq}, \]

where \( \kappa \) is the work hardening-softening function, \( \tau_{eq} \) is the threshold stress for microcrack growth function, \( A \) is an ANN approximation which keeps the effects of equivalent plastic strain, strain rates and temperature on flow stress (from experiment), while functions \( \xi_\kappa, \xi_{eq} \) introduce the phenomenological scaling only due to anisotropic microdamage effect. It can be easily shown that such result is in agreement with previously used explicit functions \([8]\) (obtained from micromechanics considerations at the level of single void \([1]\)), assuming that the influence of strain rate is different for both functions but finally giving the same approximation \( A \).

We have used the ANN with single hidden layer (16 neurons) using constrained truncated Newton algorithm for learning. The input consisted of equivalent plastic strain, strain rate and temperature while target consisted of corresponding flow stress. Both input and output were directly taken from experimental (isothermal) curves. The introduced ANN approximation allows us to reduce the material parameters to 18.

In Fig. 1 the strain-stress relations for different temperatures and strain rates taken from experiment \([6]\) (red lines), their ANN approximation (black lines) and extrapolation (blue lines) are presented.

4. Numerical examples

The application of discussed material model with identified material parameters for modelling of high speed machining problems will be presented.

![Figure 1: The strain-stress relations taken from experimental results \([6]\) (red lines), ANN approximation (black lines) and extrapolation (blue lines)](image)

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References


