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An inverse thermal–mechanical analysis of the hot torsion test for calibrating the constitutive parameters

S. Khoddam [a,*], P.D. Hodgson [b], M. Jafari Bahramabadi [a]

[a] Department of Mechanical and Aerospace Engineering, Monash University, Clayton, Victoria 3800, Australia
[b] Centre for Material and Fibre Innovation, Deakin University, Geelong, Victoria 3217, Australia

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ABSTRACT

One of the key tasks for mathematical representation of a constitutive model is calibration of its parameters. An inverse computational–experimental solution with the data modelling approach was employed here to estimate the parameters of a hyperbolic sine type constitutive equation. The solution utilizes a multi-layer constitutive model. The computational component of the inverse solution includes a rigid viscoplastic finite element code based on the thermo-mechanical coupling. The hot torsion test data comprises the experimental component of the inverse solution. Determination of the primary constitutive parameters (PCPs) pertinent to a 303 Austenitic stainless steel is presented here as an example. In order to facilitate the calibration of the sub-models, a procedure to provide an initial guess vector for the secondary constitutive parameters (SCPs) is given.

1. Introduction

There has been an increasing need for the accurate prediction of material behaviour under high deformation and high temperatures. Given a suitable constitutive model, the requirement reduces to the precise calibration of the parameters in the model.

A significant number of constitutive models in the current literature do not have adequate internal variables incorporated in them. Although such simplistic models may be phenomenologically justifiable, the models are not generally reliable beyond the range of experimental conditions for which they were verified. The challenge is particularly acute when predictive capability is sought.

Unified modelling of the constitutive behaviour of materials has been actively developed for the improvement of industrial forming processes when varying deformation conditions are involved (e.g. [1]). A unified model has a multi-layer structure including a heirearchy of models and sub-models. In practice, the constitutive parameters in the first layer are not constant and change with strain, strain rate and temperature. For the sake of classification, we will be referring to the first layer parameters as *primary* and to those appearing in the sub-models as *secondary parameters*. In a sub-model, secondary constitutive parameters (SCPs) define variations of the primary constitutive parameters (PCPs) with strain, strain rate and temperature. Both data modelling based [2] or phenomenologically based [3] approaches have been used in the existing literature for unified constitutive modelling. Also the integrated phenomenological–artificial neural network models have been developed [4] from the Estrin–Mecking phenomenological model [3] and a back-propagation artificial neural network model. The challenge is partly due to evolution of the internal structure with time through hardening and softening mechanisms such as work hardening, recovery and recrystallization, and the flow curve shape partly depends on the competition between these phenomena. A phenomenological constitutive description for the hardening and softening mechanisms of fcc metals was developed by Nes [5] in which a statistical approach to the storage of dislocations was used. Both data modelling and phenomenological approaches introduce a number of parameters and the common challenge for both approaches is the calibration of their parameters based on the experimental data.

Calibrating the constitutive parameters by applying the experimental data has been performed using a *forward problem* and *inverse solution* techniques. The former utilizes an existing closed-form solution for a mechanical testing, such as hot torsion, tension and compression test, and the constitutive data obtained from the test will be used to calibrate the material parameters. The latter, inverse solution of the problem (see for example [6]), uses the experimental data for calibration of the physical parameters which characterize a model in a forward problem. In this technique, the forward problem has typically been formulated in details using a sophisticated numerical technique such as finite-element method.

Hot torsion test is one of the key tests for constructing a unified constitutive model and for identifying the parameters in the model and its sub-models. However, the existing closed-form solutions for the test do not include important details of the hot deformation

* Corresponding author.

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