Journal of Materials Processing Technology 238 (2016) 315–324

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

# Post necking characterisation for sheet metal materials using full field measurement

Stefan Marth*, Hans-Åke Häggblad, Mats Oldenburg, Rickard Östlund

*Division of Mechanics of Solid Materials, Luleå University of Technology, SE 971 87 Luleå, Sweden*

ARTICLE INFO

*Article history:*
Received 25 September 2015
Received in revised form 12 July 2016
Accepted 19 July 2016
Available online 21 July 2016

*Keywords:*
Localised necking
Stepwise modelling
Optical full-field measurement
Hardening characterisation
Boron steel

ABSTRACT

A precise prediction of the post-necking behaviour of materials is needed to increase the precision of computer simulations with large deformations. Applications in which this need is encountered include crash, forming, and failure simulations. By using an optical full-field measurement of the localised deformation field, an effective and computationally fast method is presented to determine the relationship between true stress and true plastic strain, including post-necking behaviour. The presented stepwise modelling method is used to characterise heat-treated boron steel using thin sheet metal specimens. These results are validated with the results determined by a method based on inverse modelling. It can be concluded that the stepwise modelling method is considerably faster than the compared inverse modelling method. The method is also suitable for effectively determining element size dependency due to regularisation of the hardening behaviour needed for finite element analysis with strain localisation, e.g., for crash simulations.

## 1. Introduction

The advanced use of modelling and simulation for crash tests and other situations where very large strains occur increases the demand for reliable and precise material models which reproduce material behaviour in the post-necking regime until fracture occurs. To obtain the stress–strain relation for materials beyond necking the classical methods such as tensile tests are not sufficient (Davis, 2004). Zhano and Li (1994) introduced a method that uses inverse modelling by using only the force and displacement curves to adjust the stress–strain relation comparing the results from of the finite element method (FEM) with those from experiments. This method achieves high accuracy using only a small number of test parameters. An overview of different inverse modelling methods is given by Ponthot and Kleinermann (2006). However, computations in inverse modelling are very costly (Avril and Pierron, 2007) and always require a parameterised evolution model fitted to experimental data (Tarantola, 1987).

In this paper, a computationally fast method that uses the local strain field on the tensile specimens' surface to determine stepwise the stress–strain relation is introduced. The method is only used to characterise the plastic behaviour of the material. Effects such as damage or softening are not considered in the model. To obtain the local strain field on the tensile specimens' surface Digital Image Correlation (DIC) is used, as presented by Eman et al. (2009). The material model used is based on the assumption of isotropic plastic material behaviour. The presented method minimises the deviation between the experimentally obtained force-elongation relation and the calculated force-elongation relation by varying the hardening modulus stepwise during the procedure. Since the analysis length is the limiting factor in Digital Speckle Photography (DSP), the results are dependent on this analysis length. This method can be used to obtain the stress–strain relation for different mesh size in order to obtain a stress–strain relation that is independent of mesh size in finite element analysis (FEA). Using these results, fracture models based on different mesh sizes can be adjusted; for example, the OPTUS model introduced by Häggblad et al. (2009).

## 2. Method

The basic behaviour of materials is investigated by performing standard tensile tests. A load is uni-axially applied to material specimens with circular or rectangular cross-sections. Simultaneously, the extension of the gauge length is measured and recorded by an extensometer. This extension is divided by the initial gauge length to determine the engineering strain. This method works as long as

---

* Corresponding author.
*E-mail address:* stefan.marth@ltu.se (S. Marth).
*URL:* http://www.ltu.se/staff/m/matesr-1.114397 (S. Marth).

http://dx.doi.org/10.1016/j.jmatprotec.2016.07.036

the deformation is uniform over the whole gauge length. As soon as local necking occurs, this method is not relevant (Davis, 2004).

Tensile testing provides accurate knowledge of the material properties for strains up to necking, where the strain is calculated by using gauge length and elongation and the stress is calculated by measuring the force divided by the cross-sectional area (Davis, 2004). This is sufficient for many purposes in engineering and simulation, but not if large strains are to be simulated. This can be the case for simulations of forming processes, crash tests, or other destructive processes. If these kinds of processes are simulated, the precise material properties for large strains must be known to obtain accurate results from simulations.

### 2.1. *Stepwise modelling method*

The stepwise modelling method to determine the constitutive stress–strain relation is shown in the flow chart in Fig. 1. The different steps of the method are described in this section. This method is implemented to analyse tensile tests with sheet metal specimens of different geometries.

In Fig. 2, the arrangement for an experiment with DSP is shown. The specimen has a stochastic pattern on the surface, which is photographed by a high-speed digital camera at a certain frequency. This pattern can be applied in different ways; it can be sprayed with black and white paint or sandblasted to generate a random pattern that can be detected by the camera system. These images are synchronised with the measured force and elongation values and stored on a computer which uses Digital Image Correlation (DIC). DIC is described in the following section and is used to determine the deformation field of the specimen. During the testing process, the reaction force and the elongation are measured and saved together with the image data on the computer. The frame rate depends on the strain rate in the test. Usually, there are series of 50–100 images per tested specimen.

### 2.2. *Digital Image Correlation*

Digital Image Correlation is an optical non-contact method used to determine the displacement of points on a surface by comparing a random speckle pattern (shown in Fig. 3a) over a series of images from different deformation stages. Before a load is applied, a reference image is taken against which all other images in the

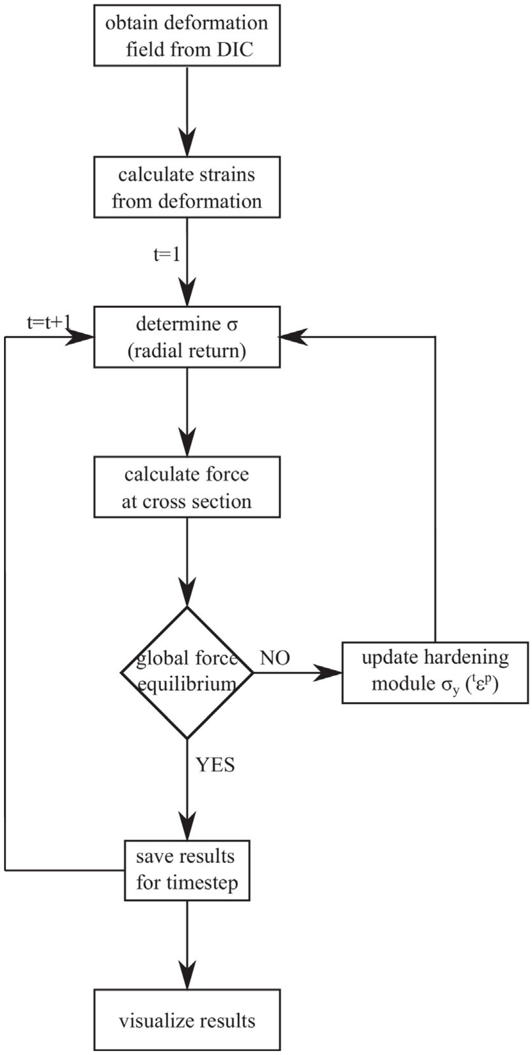

**Fig. 1.** Flow chart of the stepwise modelling method used to obtain the constitutive stress–strain relation.

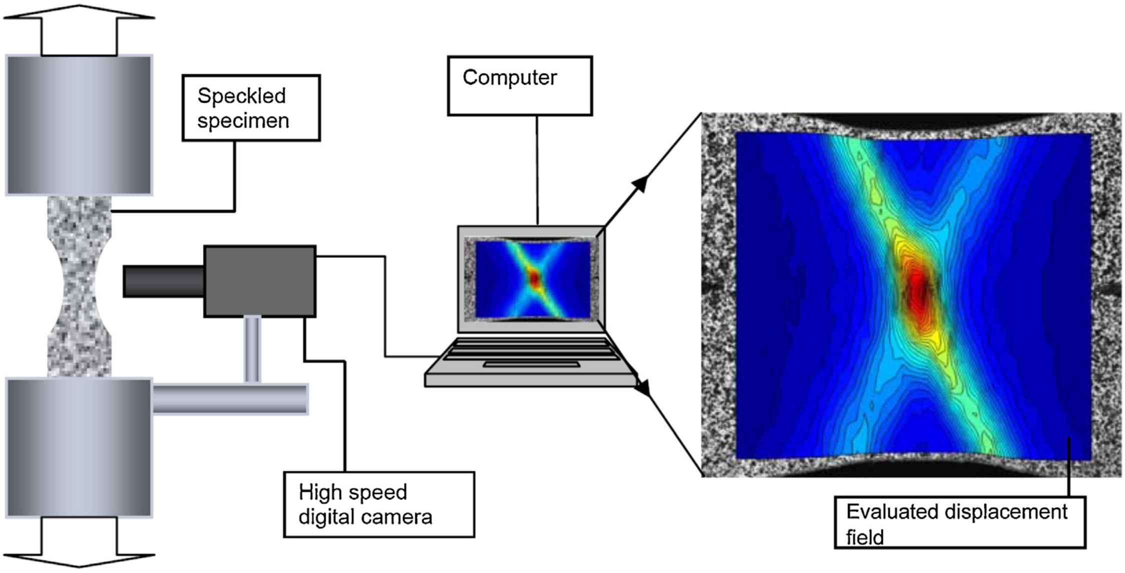

**Fig. 2.** The experimental arrangement used for speckle photography (Eman et al., 2009).