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Computer-aided identification of the yield curve of a sheet metal after onset of necking

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Abstract

By the computer-aided method of material characterization many complex identification cases, where classic experimental–analytical methods of physical properties identification fail, can be successfully solved. Such an example is the standard tensile test of a flat steel sample, where the yield curve cannot be identified after the occurrence of the necking phenomenon. Yet, in deep drawing of metal sheets, strains and stresses beyond the limits derived by classic analytic expressions upon the tensile test measurements are often met. In order to enable physically objective numerical simulations of those processes, reliable material properties data must be provided. To cope with the problem of the extended yield curve identification, a special combined experimental/numerical technique has been developed. The technique relies on the comparison between the real material response, measured by the standard tensile test, and the response, obtained from a numerical simulation of the same test under assumption of a prescribed material behaviour. By proper tuning of some characteristic parameters of this tentative material behaviour law, the numerical response can be drawn close to the measured one. For this purpose a special numerical approach, based on mathematical optimization methods is employed.

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1. Introduction

A modern cost-effective mass production of industrial goods sets high demands regarding quality of the materials used. Here included is the uniformity of the respective physical properties that are relevant for a successful and stable product making. There are many products, like in sheet metal forming, where during the production process limits of the material capability are almost exhausted. Aiming at avoiding eventual failure of a product, several precautionary measures are undertaken already at the technology design stage, including also a numerical simulation of crucial phases of the production process. The degrees of

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numerical accuracy and physical objectivity of the performed numerical simulations depend on many parameters, which are to be carefully defined by the analyst. Among them the material data parameters play an essential role, especially in numerical simulations of metal forming, where intensive material flow occurs, and its evolution is rather susceptible to the data variation. This is due to the fact that the problem is computationally highly nonlinear, both kinematically (large displacements and large strains) and materially (large inelastic deformation). To describe the behaviour of such materials also at high strain values properly some specially designed experiments should be carried out [1–6].

Traditionally, the characterization of material properties is carried out by adequate standardized experiments, where a high degree of uniformity of the quantity of interest (e.g. stress, strain, temperature field) is obtained inside the sample. Then, a limited number of material parameters are analytically derived from the obtained test data [7].

Opposite to this experimental practice, the so-called *non-trivial experiments* [8], where inhomogeneous, transient and/or multiaxial fields exist in the sample, represent, when coupled with appropriate numerical methods, an alternative means for the solution of some characterization problems. In fact, as the mechanical state inside a sample is complex, the values of the material parameters cannot be derived from the experiment by simple analytical expressions. Instead, a computer simulation of the real experiment based on a corresponding numerical model is needed. Namely, when performing the simulation under the same conditions, that specify the real experiment, it is possible, by imposing equivalence of the computed and the measured responses, to identify material properties. Presuming that in the numerical model, whose boundary conditions are not subject to change, the response is solely dependent on the assumed material data, it can be correspondingly adjusted to yield equivalence to the experiment exclusively by an adequate variation of the assumed material parameters. The indispensable task of the analyst is to hold the aforementioned presumption true by taking into account all common rules of numerical modelling (problem domain and time discretization, appropriate numerical method choice, etc.).

In the evaluation of the experimental data the computer-aided rheology assistance has been present for a long time, its role in the material characterization being most significant. Nowadays, when considering recent advances in computational techniques for the solution of inverse problems, this assistance becomes even more firm and efficient [5,6,9].

2. Problem description

The tensile test is the most often used mechanical test for identification of the yield curve. Assuming homogeneous strain and stress fields in the parallel central part of the sample, considered in the experiment as domain of inspection, the logarithmic strain in the longitudinal direction φ and true (Cauchy) stress σ is obtained from the following equations:

$$\varphi = \ln\frac{l}{l_0}, \quad \sigma = \frac{F}{A}, \tag{1}$$

where l_0 and l represent respectively the initial and the instantaneous length of the inspected domain, measured by an extensometer, F the applied force and A the actual cross-sectional area of the sample. Then the yield curve can be drawn in a diagram as a plot of σ against φ. This experimental–analytical method of the yield curve identification is simple and works well until the assumption of the stress and strain fields homogeneity in the observed domain is valid. This assumption will be definitely violated if geometric instability in a form of necking of some localized portion of the sample occurs. In that case, with the continuation of the sample's extension, the inhomogeneous strain field will develop in the neck region. All further deformation will be localized in this instability region with the neck becoming more and more pronounced. Also, the stress field in the necking region will change from a homogeneous and uniaxial field prior to the necking to a triaxial one. The rest of the sample, however, will still experience a homogeneous and uniaxial stress field.