CALIBRATION OF ANISOTROPIC ELASTIC- PLASTIC MODELS FOR THIN LAYERS AND FOILS IN MICROTECHNOLOGIES: TWO NOVEL TECHNIQUES

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Summary The methods presented in this paper for the identification of material parameters in anisotropic elastoplasticity at the microscale exhibit the following new features in their experimental stage: data gathered from both indentation curves and imprint mapping in the former technique, which is intended for the mechanical characterisation of thin layers on substrate; in the latter, a device which pressurises a free foil specimen and measures the geometry of the inflated membrane by a laser profilometer. At the computational stage, traditional least-square techniques are employed for the inverse analysis based on finite-element large-strain simulations, which are used also for sensitivity analyses.

INTRODUCTION

Anisotropy in elastic and inelastic mechanical behavior of materials is often a consequence of fabrication processes. In particular thin foils produced by laminations usually exhibit significantly different stiffness and strength properties in the "machine direction" and in the "cross direction".

Current research motivated by real-life industrial problems has led to the two model calibration methods presented herein, both centered on the integration of new experimental procedures and traditional inverse analysis techniques. In both engineering situations considered the material behavior is assumed to be elastic-plastic, ductile, orthotropic and realistically described by the classical constitutive model proposed by Hill in 1974 [1]. In both cases the computer simulation of the experimental tests are performed by a commercial finite element code in finite strains [2] and the identification of parameters is carried out by means of a deterministic batch approach; see, e.g., [3, 4]. The proposed methods are validated by means of "pseudo-experimental data", namely by using measurable quantities computed on the basis of assigned parameters which must be recovered through the inverse analysis.

INTEGRATED INDENTATION TEST OF THIN LAYERS

The first method considered is intended for thin layers which may adhere on a substrate. The experimental stage consists of a conventional micro-indentation test performed by an axi-symmetric indenter followed by the mapping of the residual imprint, the geometry of which is defined through a number of measurements by means of suitable instruments; specifically, in the present study, an atomic force microscope (AFM) is considered. The gathered experimental information, namely "indentation curves" (force versus penetration depth) and imprint mapping, see Figure 1, are input into the inverse analysis stage, namely: a norm of the discrepancy between the available experimental data and their computed counterparts is minimized with respect to the parameters to identify, which are contained in the material model adopted and implemented for the computer simulation of the test.

In this study comparative assessment of merit are presented of various identification strategies and algorithms and of sensitivity computations as guidelines for the experiment design. The main novelty of the proposed methodology (at present motivated primarily by the industrial production of MEMS) rests on the combined use of indentation, imprint mapping and inverse analysis: this combination permits the quantitative characterization of local inelastic anisotropy at the micro and nanoscale, which is not recoverable from indentation curves only; see, e.g., [5, 6].

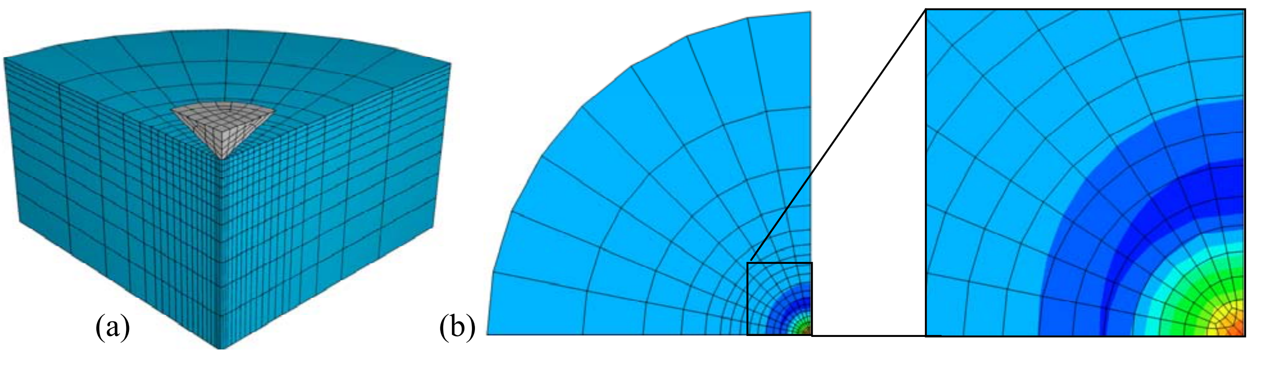

Figure 1: Finite element model of indentation test (a) and contours of the imprint mapping (b).

MEMBRANOMETER TEST ON FREE FOILS

The second method presented herein concerns free anisotropic foils, e.g. those produced by the paper industry and the ones of aluminum and polyethylene employed in laminates for food containers. A new experimental instrumentation, called "membranometer", is proposed, see Figure 2: the foil to be mechanically characterized is placed over a circular window and is inflated by a pressurized fluid; for each pressure level the deformation process of the inflated sheet is monitored by a "profilometer" placed above the foil specimen and simulated by a finite element technique; the discrepancy between the measured and computed displacements under given pressures is minimized with respect to the parameters in the material model adopted for the finite element simulation; the estimates of these parameters are provided by the computer post-processor.

The inverse and the sensitivity analyses are performed by the same approach previously outlined; various techniques comparatively discussed in this study validated the proposed methodology. A prototype of the novel experimental equipment is being designed and constructed by colleagues in the Mechanical Engineering Department for a preliminary validation of the proposed experimental technique.

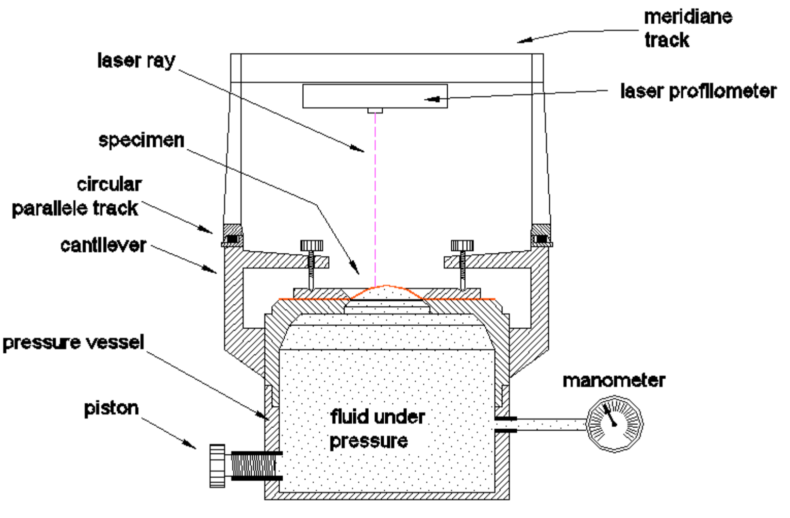

Figure 2: Schematic representation of the membranometer.

CONCLUSIONS

The two methods proposed for the calibration of inelastic material models in thin layers and foils exhibit the following novelties: imprint mapping as supplement of indentation curves in the former; mapping of the inflated membrane in the latter. The inverse analysis stages are based on rather traditional least-square approach; however, stochastic approaches like extended Kalman filters are envisaged for the sequel of this study. Both proposed methods turn out to be promising in terms of cost-effective, fast and routine use in industrial environments.

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