Elastic and Elasto-Plastic Material Parameter Identification by Inverse Modeling of Static Tests using Digital Image Correlation

Abstract

This thesis evaluates the possibility of identifying elastic and elasto-plastic material model parameters by inverse modeling (Finite Element updating) of static mechanical tests, using the digital image correlation measurement technique. The presented technique derives the different material properties or model parameters from the measured strains at the surface of a loaded specimen. The results show that the method is able to identify the in-plane elastic properties of both isotropic and orthotropic composite materials, performing a single mechanical test, i.e. a biaxial tensile test. Based on that same test it is also possible to retrieve the plastic model parameters of an orthotropic yield surface and an isotropic hardening law, in the case of sheet metals.

Summary

In order to numerically simulate mechanical behavior of materials with sufficient accuracy and computational efficiency, it is necessary to develop appropriate constitutive models. All such models contain a number of material parameters which are to be determined from some kind of experiments with material specimens.

A direct problem is the classical problem where, in the field of mechanical engineering, a given process or experiment is simulated in order to obtain the geometry of the considered object and the stress-strain distribution in the final configuration as well as its evolution during the process of deformation. The success of such an analysis largely depends on the reliability of the applied constitutive models and on the accuracy of the estimates of the parameters in these models. Most standardized methods for the determination of constitutive material model parameters are based on the use of test specimens with a well-defined standardized geometry and loading, so as to induce particular conditions on the obtained stress and strain field, which are satisfied in at least a part of the specimen. Uni-axial tensile and compression tests, plane strain tensile tests, torsion and bending tests are suchlike experiments that allow the determination of the unknown material parameters. Relatively simple analytical relations can be used accordingly to determine the unknown material parameters from the measurement of variables such as forces, torque's, displacements and twist angles.

Inverse problems are concerned with the determination of the unknown state of a mechanical system considered as a "black box", using information gathered from the responses to stimuli on the system. For inverse problems, certain input data of the direct problem is deduced from the comparison between the measured responses and the results of a FE-simulation of the same experiment. Generally, experimental data comes from the analysis of both the thermo-mechanical stimuli and their responses on the boundary of the solid. Nowadays, however, not only the boundary or global information is used, but relevant information resulting from full-field surface measurements is also integrated in

the evaluation of the material models. In most application examples of inverse methods, the experimental set-up is based on that of standard methods, but the stress-strain state is no longer assumed to be homogeneous. Full-field measurement techniques allow for the use of measurement information obtained from real-life processes or from experiments, especially designed to approach the actual stress and strain distributions more closely than conventional experiments.

The inverse method described in this work can actually be narrowed to parameter estimation, as the only item of interest to this study is the determination of the constitutive model parameters. The values of these model parameters cannot be derived immediately from the experiment. A numerical analysis is necessary to simulate the actual experiment. However, this requires that the material parameters are known. The identification problem can then be formulated as an optimization problem, in which the material parameters are updated and where the function to be minimized is some error function that expresses the difference between simulation results and measured data.
The aim of optimization in inverse modeling, is to efficiently reduce the discrepancy between experimental end simulated results by adapting the set of model parameter values. In order to quantify the quality of the agreement between the measured and calculated responses, an objective or cost function has to be defined. These functions exist in different configurations and embrace several possible estimators. Furthermore, these functions can be subjected to constraint functions which should not be active at the optimum but which allow limiting the search domain of optimal parameters to physically reasonable values.

The development of effective whole-field measurement techniques, such as moiré and speckle interferometry, digital image correlation, etc., together with efficient digital data treatment, has disclosed a new area of testing procedures to identify constitutive equations of materials. Indeed, conventional test methods rely on uniform and pure stress states (tension or compression on rectangular specimens, torsion on bars and rods, bending of beams etc.). The need for such simple test configurations arises from the limited strain information obtained from strain gauges or extensiometers. The availability of full-field displacement and strain measurements at the surface of specimens, changes this approach completely.