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Mechanical Characterization of Composites and Biological Tissues by Means of Non-Linear Filtering

M.A.N. Hendriks, C.W.J. Oomens, J.D. Janssen and J.J. Kok

Eindhoven University of Technology, The Netherlands

Introduction

Constitutive models to characterize fibre-reinforced composites and biological tissues are complex and usually contain a large number of parameters. A common way to measure these parameters is to load samples of a simple shape in such a way, that a homogeneous stress and strain distribution is obtained in some part of the sample. In this way a direct coupling between stress and strain is possible. However, such a procedure has disadvantages when used for composites or biological materials:

- Due to the complex mechanical behaviour it is hardly possible to create a simple stress and strain field. Hence the field equations can only be solved numerically.
- As many unknown parameters are to be determined (due to anisotropy, non-linear visco-elastic behaviour) the number of experiments needed for a sufficient characterization is enormous.
- Most biological materials have inhomogeneous properties, so homogeneous strain distributions can not be obtained.

Here we follow a different approach, which does not require a homogeneous strain distribution. It is assumed that measurements of the strain distribution are available and that the field equations can be solved numerically.

Theory

Assuming that a constitutive model for the material under investigation and a numerical procedure to solve the field equations are available, the problem is to find a column $\underline{x}$ of unknown parameters from the equation:

$$\underline{y}(t) = \underline{Y}(\underline{x},\underline{w}(t),t) + \underline{v}(t) \qquad (1)$$

where: $\underline{y}$ = a column of measured displacements, $\underline{w}$ = a column of model errors, $\underline{v}$ = a column of measuring errors, t = time, $\underline{Y}$ = some non-linear function. The function $\underline{Y}$ is not explicitly available, but we assume that it is possible to calculate $\underline{y}$ for given $\underline{x}$ by means of some numerical procedure, such as the finite element method.

Making use of an approximate non-linear filter procedure (Jazwinski, [1]) we obtain minimum variance estimates for the parameters, $\hat{\underline{x}}$:

$$J = \text{Expectation}\{\ (\underline{x}-\hat{\underline{x}})^T(\underline{x}-\hat{\underline{x}})\ \} \rightarrow \text{minimum} \tag{2}$$

Example

The procedure has been used to characterize a transversally isotropic elastic material. Figure 1 shows a simulation of an experiment by means of a finite element calculation, in which plane stress is assumed. The displacements of the markers, artificially disturbed with noise, are used to determine four parameters out of one single experiment. Figure 2 shows the estimates for the model parameters as a function of the number of finite element calculations used in the optimization process. The horizontal straight lines indicate the real values of the parameters.

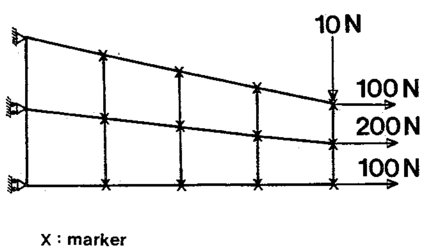

figure 1

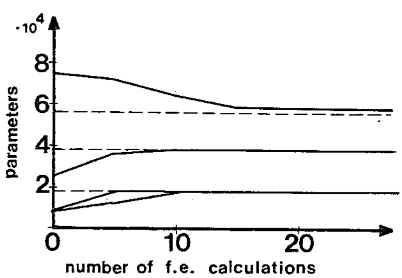

figure 2

This and other experiments showed that the method offers an interesting tool for a quick characterization of complex materials.

References

1. Jazwinski A.H.: Stochastic processes and filtering theory. New York and London: Academic Press 1970