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A Framework for the Automated Data-Driven Constitutive Characterization of Composites

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SUMMARY

We present advances on the development of a mechatronically and algorithmically automated framework for the data-driven identification of constitutive material models based on energy density considerations. These models can capture both the linear and nonlinear constitutive response of multiaxially loaded composite materials in a manner that accounts for progressive damage.

Keywords: Energy density, Data-Driven, Framework, Constitutive behaviour, Material characterization, Inverse methods, Multi-axial loading, Progressive damage.

APPROACH

Instead of following the standard hypothetico-deductive scientific method, of hypothesizing and analytical modelling and then attempting its validation through experimentation our framework follows the industrial-inductive scientific method in order to take advantage of its built-in validation characteristics [1]. This is achieved because the analytical model representing the constitutive behaviour of the material is built by an inverse methodology based on systematically acquired experimental data that express energy balance considerations.

The description of the intensions and the current status of our methodology utilizing a custom made mechatronic system (see Fig. 1) capable of applying 6 Degrees of freedom (DoF) kinematic constrains is given as an extension of the pioneering research with 3-DoF mechatronic systems for the case of in-plane loading [1,2] initiated at NRL in the early 70s.

A description of the overall methodology for exploiting the acquired data that encapsulate the kinematic and strain field response of the specimens is also given in the present paper. Special emphasis is given onto the description of the load displacement data as well as a Mesh Free Random Grid Method developed and applied for optically measuring the corresponding strain fields.

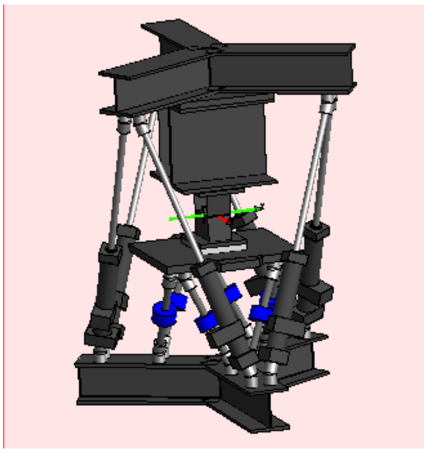

Figure 1. 3D view of NRL's 6-DoF mechatronic testing frame.

An inverse problem is formulated on the basis of the energy balance between internal energy and external work of the specimens under multi-dimensional loading conditions. The aim of the inverse problem is to determine all the material parameters that allow the full determination of the analytical formalisms of the constitutive functionals for both the elastic and inelastic behaviour of the material system used to construct the specimens at the bulk lamina level. The algorithmic character of the problem is described as a design optimization problem where the associated objective function to be minimized represents the norm of the error vector expressing the difference between the experimentally measured and the analytically computed energy stored into the system and spent by all associated dissipative mechanisms including irreversible progressive damage.

An example of applying this approach from the perspective of synthetic experimental data is given to demonstrate the feasibility of the underlying method. Demonstration of the applicability of the methodology for describing the non-linear behaviour of composite laminated inside and outside the linear regime is also presented.

Finally the progressive damage and failure implications of this approach are discussed in the context of simulating the behaviour of the specimens used to characterize the material system involved.

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