PhD thesis

Title: Dynamic analysis of non linear structures and materials by using fractional constitutive models and multiphysics approach.

Keywords: non-linear constitutive equation, viscoelastic material, experimental characterization, dynamic analysis, fractional calculus, variable fractional order viscoelastic model, numerical solution

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Context

Fractional calculus has been well developed in recent years and it becomes a kind of powerful mathematical tool to solve the mechanical problems, specifically in the characterization of materials' viscoelastic properties. Fractional calculus is devoted to the study and application of derivative and integral of arbitrary (real, complex or function) order. The fractional derivative model can easily and simply describe the real dynamic behaviour.

The mechanical properties of the polymers and their composites (for example, polymers loaded with carbon nanotubes) need to be well investigated to extend their applications in the field of manufacturing engineering and design of smart materials (for example presenting sensing capacities due to their piezo-resistive response). The classical material models, such as viscoelastic, hyperelastic and viscoplastic models, have been widely used to describe the physical behaviours of these materials. These models are usually established based on the integer order equations. The fractional order models are less used in the numerical simulation of materials' properties. Inside composite, the coupling between materials and their interfaces involves multi-physical phenomenon which represents challenging scientific issue. The major difficulties are the establishment of the governing equations based on fractional order material model and resolving the equations with an effective algorithm with high accuracy.

Objective

The objective of the thesis is to propose the material models with constant fractional order or variable fractional order to perform the dynamic analysis of the nonlinear structures. The existed viscoelastic or viscoplastic models based on the fractional order will be firstly studied in the literature. Several models will be selected according to the specification of the polymers and their composites. The mechanical testing, including the dynamic test and the static test, will be effectuated in order to identify the material parameter and the fractional order in the differential equations. According to the characteristics of the established model, suitable functions will be adopted to search the solutions, such as Legendre wavelet function, Haar wavelet function…

In this research work, the mathematical model for viscoelastic polymers based on the theory of fractional calculus will be established, then the material parameters will be characterized by the mechanical tests and finally the fractional order differential equations will be solved with polynomial functions. The polynomials can be used to approximate the unknown function on the specific interval, making it easier to solve variable fractional differential equations with physical background. Both the mathematical and mechanical capacities are desired in this research topic, especially in computational mathematics and dynamic mechanical testing.

Work program

The project will be structured as follows:

Academic year	Research work description
1st year	– State of art on material physical behaviours (viscoelastic and viscoplastic). – Proposition of suitable fractional behaviour laws for polymers and their composites – Practice the experimental tests and numerical simulation tools.
2nd year	– Characterisation of the materials' properties with the mechanical tests – Identification of the parameters in the proposed fractional behaviour laws. – Analysis of the material parameters' sensitivity (fractional order).
3rd year	– Numerical simulation with the proposed behaviour laws – Experimental validation of the numerical predictions. – Writing the Ph.D. thesis.

Equipment involved

- Tensile, compression and torsion test equipment for quasi-static testing
- Split Hopkinson Pressure Bars for dynamic compressions tests
- Differential Scanning Calorimetry (DSC)
- Dynamic Mechanical Analysis (DMA)
- Abaqus, Ls Dyna, Radioss, SolidWorks, Catia and Matlab softwares

Collaboration

This work will be conducted in collaboration with Professor Yiming CHEN, Yanshan University, China

Candidate profile:

- Mechanical engineering
- Polymer and composite properties
- Computational mathematics
- Intermediate English level
- Punctual, autonomous and dynamic

Bonus skills:

- Fractional calculus
- Knowledge of finite element method (or commercial FEM code)

References

[1] Faleh Rabhi, **Gang Cheng**, Thierry Barrière, Nourredine Aït Hocine. Influence of elastic-viscoplastic behaviour on the filling efficiency of amorphous thermoplastic polymer during the micro hot embossing process. Journal of Manufacturing Processes. 2020, 59, 487-499.

[2] Lei Wang, Yiming Chen, **Gang Cheng**, Thierry Barrière. Numerical analysis of fractional partial differential equations applied to polymeric visco-elastic Euler-Bernoulli beam under quasi-static loads. Chaos, Solitons & Fractals. 2020, 140, 110255.

[3] Jiawei Cao, Yiming Chen, Yuanhui Wang, **Gang Cheng**, Thierry Barrière, Lei Wang. Numerical analysis of fractional viscoelastic column based on shifted Chebyshev wavelet function. Applied Mathematical Modelling. 2021, 91, 374-389.

[4] Nicolas Penvern, **André Langlet**, Michel Gratton, Marcel Mansion, Nourredine Aït Hocine. Experimental characterization of the quasi-static and dynamic piezoresistive behavior of multi-walled carbon nanotubes/elastomer composites. Journal of Reinforced Plastics and Composites. 2020, 39(7-8), 299-310.

[5] Aravind-Rajan Ayagara, **André Langlet**, Michel Gratton, Nourredine Aït-Hocine. Prediction of the piezo-resistive behavior of rubber/carbon nanotube nanocomposites under quasi-static compression. To be published in 2021 in Composites Part A.

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