THE NORTHERNMOST UNIVERSITY
of Technology in Scandinavia

Identification of parameters for direct and inverted model to predict performance of materials exhibiting non-linear viscoelastic behavior

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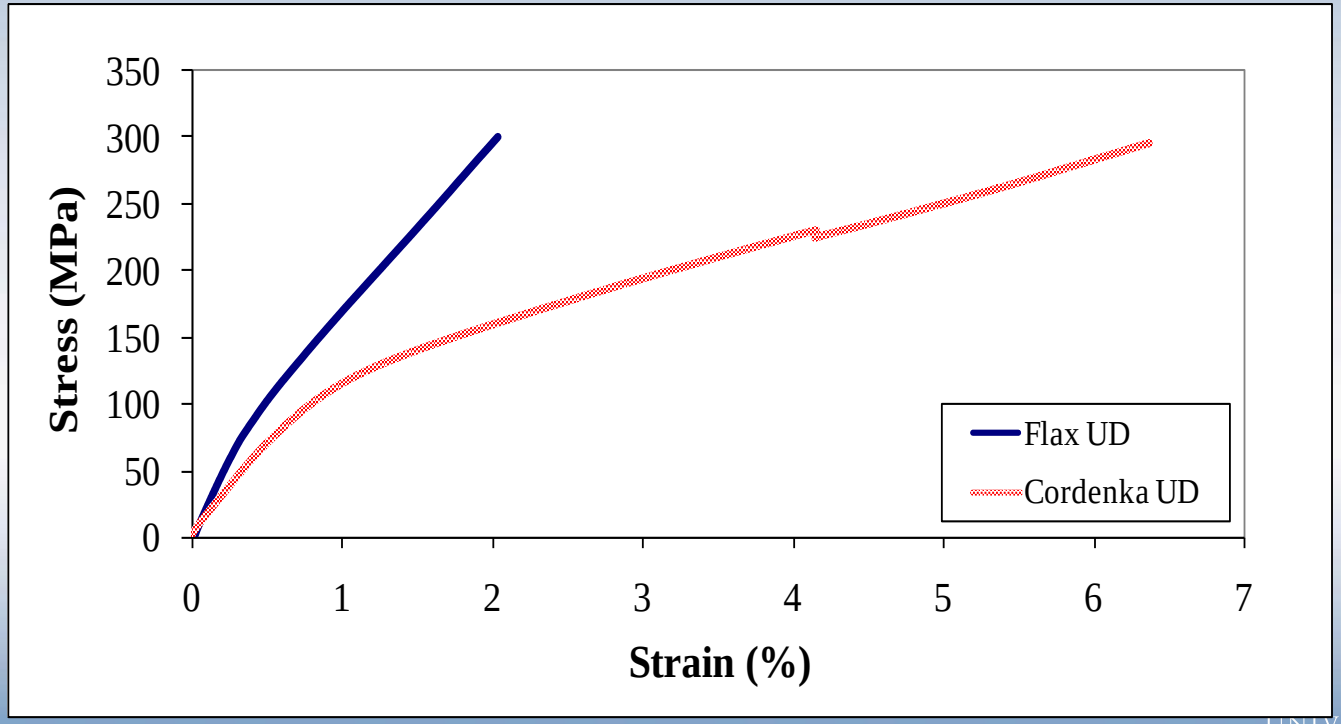
Introduction

Often multi-axial laminates as well as short fiber and natural fiber composites exhibit non-linear behavior due to properties of constituents and micro-damage.



Objective

- Develop accurate models that can predict behavior of non-linear composite materials, based on properties of constituents

Material model: stress formulation

$$\varepsilon = d(\sigma_{\max}) \cdot \left(\varepsilon_0 + g_1 \int_0^t \Delta S(\psi - \psi') \frac{d(g_2 \sigma)}{d\tau} d\tau + \varepsilon_{VP}(\sigma, t) \right)$$

Damage | **Visco-elastic** | **Visco-plastic**

$$d(\sigma_{\max}) = \frac{E_0}{E(\sigma_{\max})}$$

$$\varepsilon_{VP} = C_{VP} \left\{ \int_0^t \sigma(\tau)^M \, d\tau \right\}^m$$

$$\Delta S(\psi) = \sum_m C_m \left(1 - \exp\left(-\frac{\psi}{\tau_m} \right) \right)$$

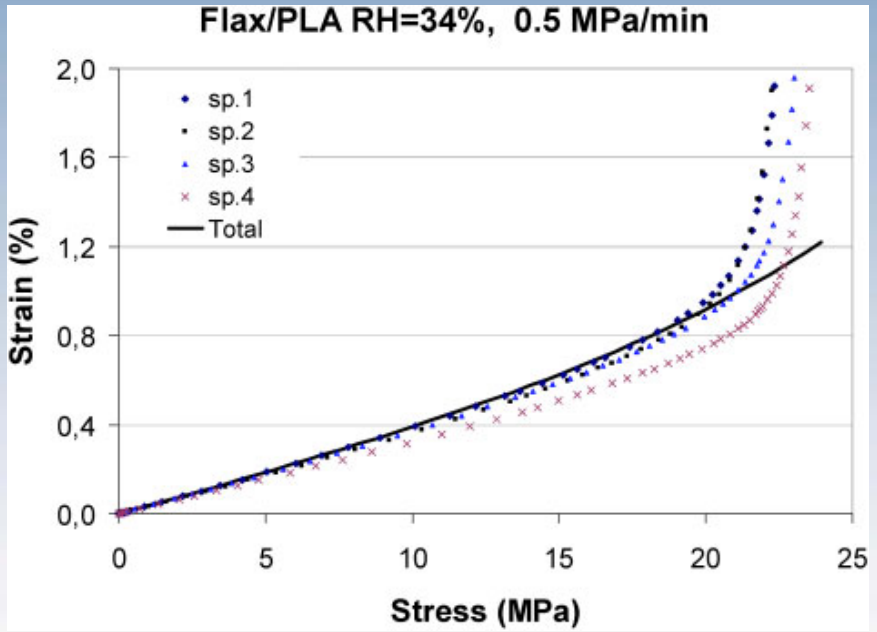
$$\psi = \int_0^t \frac{dt'}{a_\sigma}$$

Material model: stress formulation

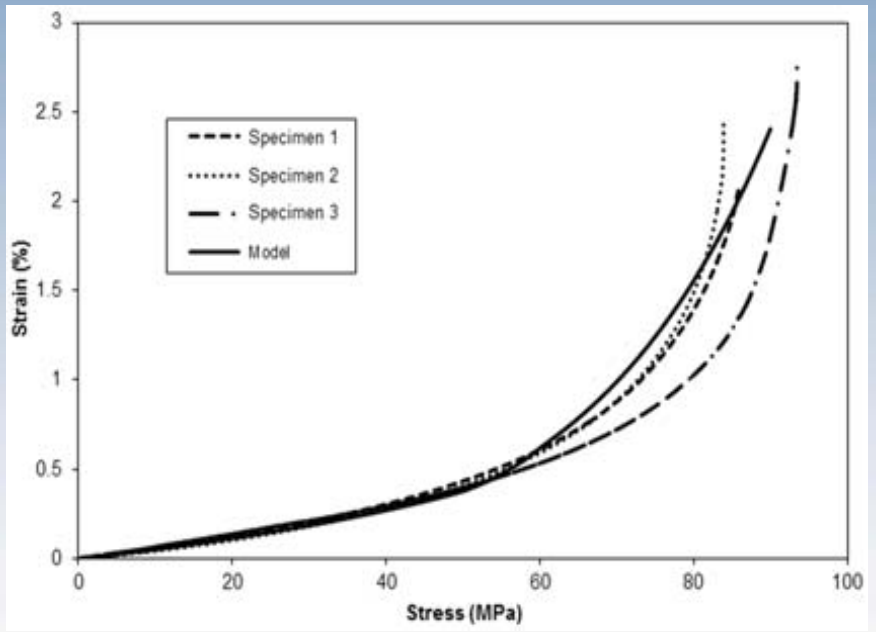
- This model predicts behavior of non-linear materials with good accuracy, however to obtain all input parameters large number of time consuming experiments must be performed:
  - **Damage** – stiffness degradation tests;
  - **Viscoplasticity** – multiple-step creep tests;
  - **Viscoelasticity** – creep tests

* Giannadakis K, Mannberg P, Joffe R and Varna J, The source of inelastic behavior of Glass Fibre /Vinilester non-crimp fabric [±45]s laminates. *J Reinf Plast Comp* 2011
* Varna J, Rozite L, Joffe R and Pupurs A, Nonlinear behavior of PLA based flax composites. *Plast Rubber Compos*, 2012;

Material model: stress formulation



Varna J, Rozite L, Joffe R and Pupurs A, Nonlinear behavior of PLA based flax composites. *Plast Rubber Compos*, 2012



Giannadakis K, Mannberg P, Joffe R and Varna J, The source of inelastic behavior of Glass Fibre /Vinilester non-crimp fabric [±45]s laminates. *J Reinf Plast Comp* 2011

Material model: stress formulation

- Simulations of strain controlled tests are needed:
  - Most of the codes for numerical structural analysis, analytical micromechanics models (rule of mixture, concentric cylinder assembly model), classical laminate theory require model, where stress are expressed as a function of strain and time;
  - Most often experiments are performed in displacement (strain) controlled mode

Material model: strain formulation

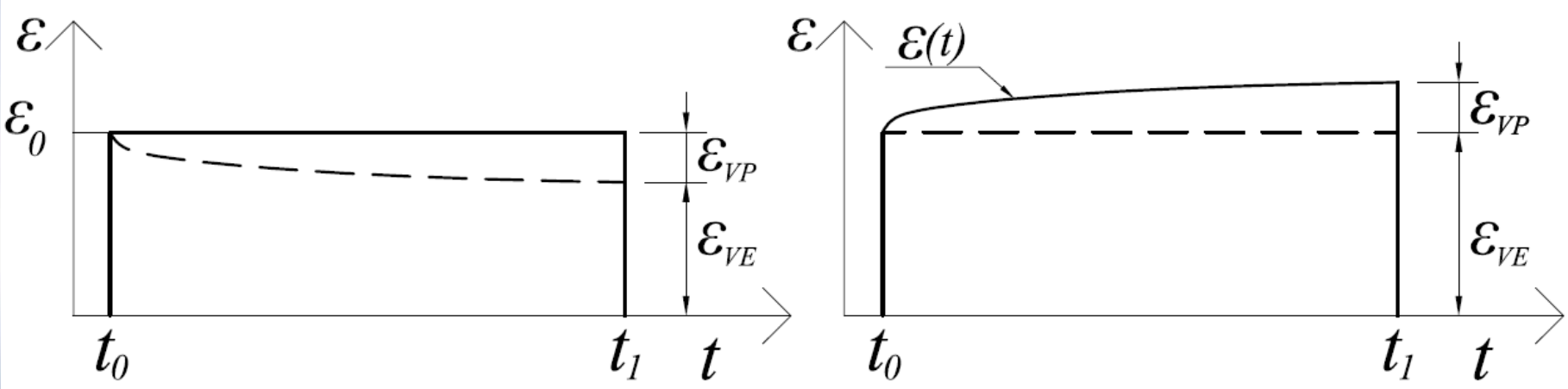
$$\sigma_{VE} = C_1 + h_1 \int_0^t \Delta E(\xi - \xi') \frac{d(h_2 \varepsilon)}{d\tau} d\tau$$

$$\Delta E(\xi) = \sum_m E_m \exp\left(-\frac{\xi}{\mu_m}\right) \qquad \xi = \int_0^t \frac{dt'}{a_\varepsilon}$$

- For non-linear viscoelastic materials both forms are not compatible
- All parameters for viscoelasticity can be obtained from relaxation tests

Material model: strain formulation

- Viscoelastic strain must be kept constant, but most of materials have also viscoplastic strain component, therefore this test can not be performed straightforward.



Material model: inverted incremental model

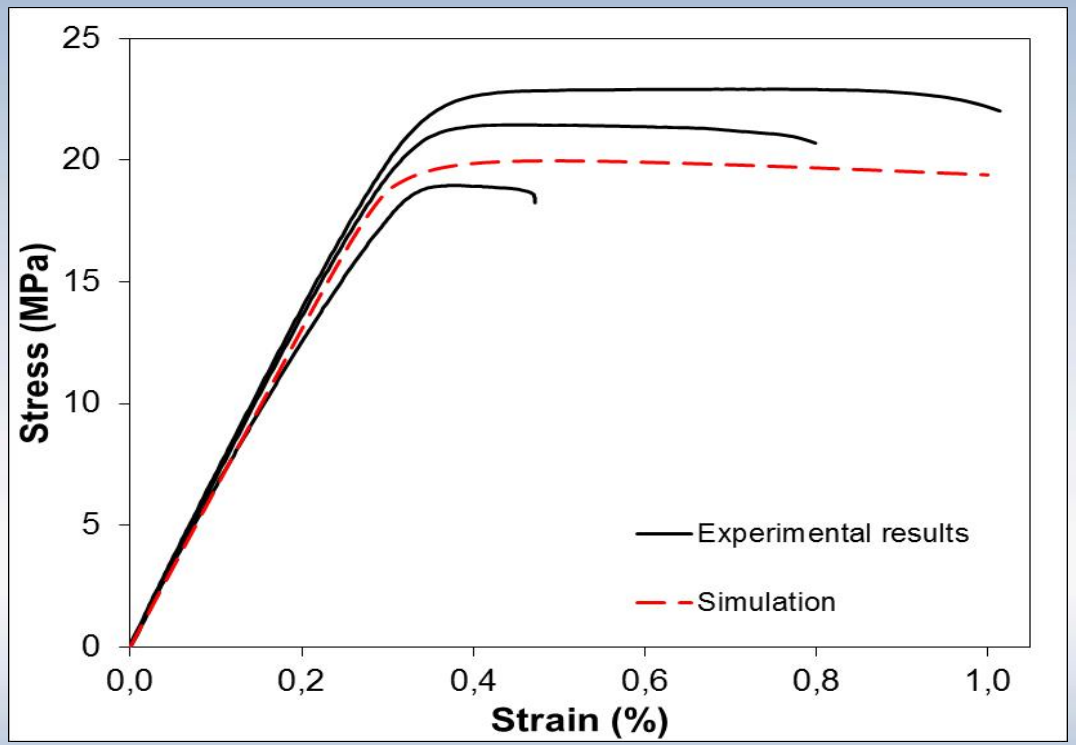
- Model has been rewritten in incremental form

$$\varepsilon^{k+1} = \varepsilon^{k} + f_1\left(\sigma^{k}, \sigma^{k+1}, g_1\left(\sigma_k, \sigma_{k+1}\right), g_2\left(\sigma_k, \sigma_{k+1}\right)\right)$$

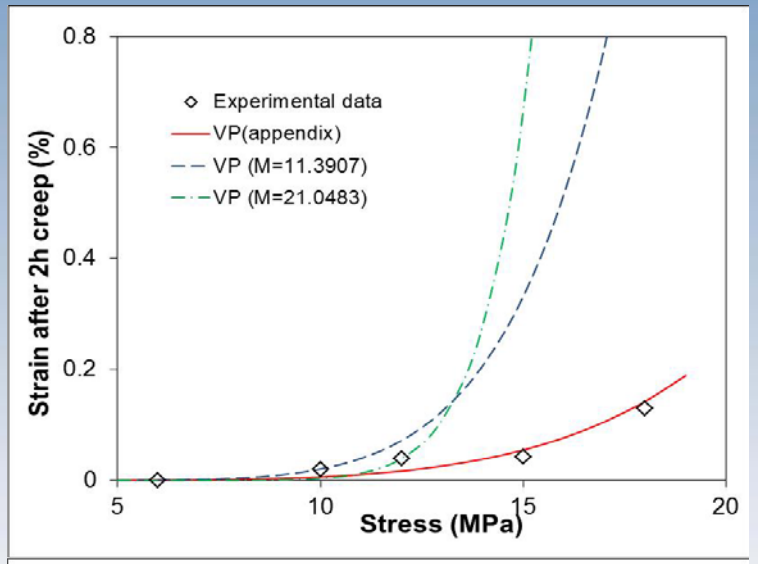
$$f\left(\varepsilon^{k+1}, \varepsilon^{k}, \sigma^{k}, \sigma^{k+1}\right) = 0$$

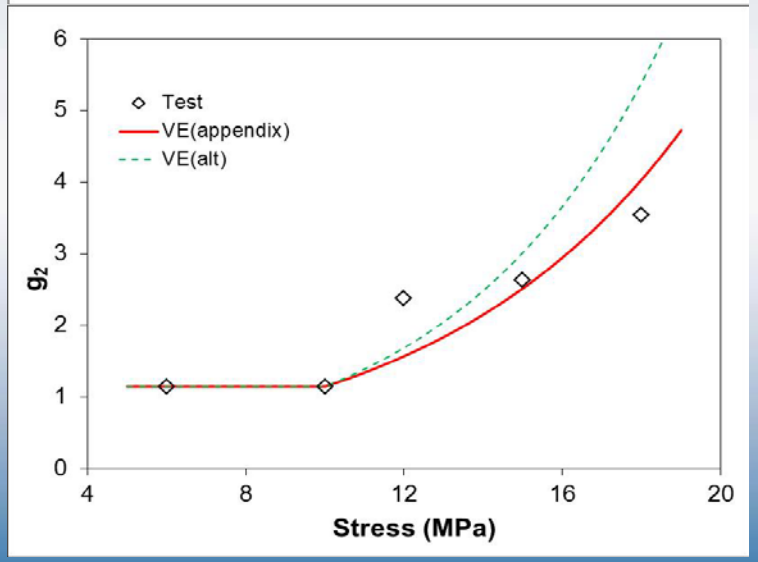
Material model: inverted incremental model

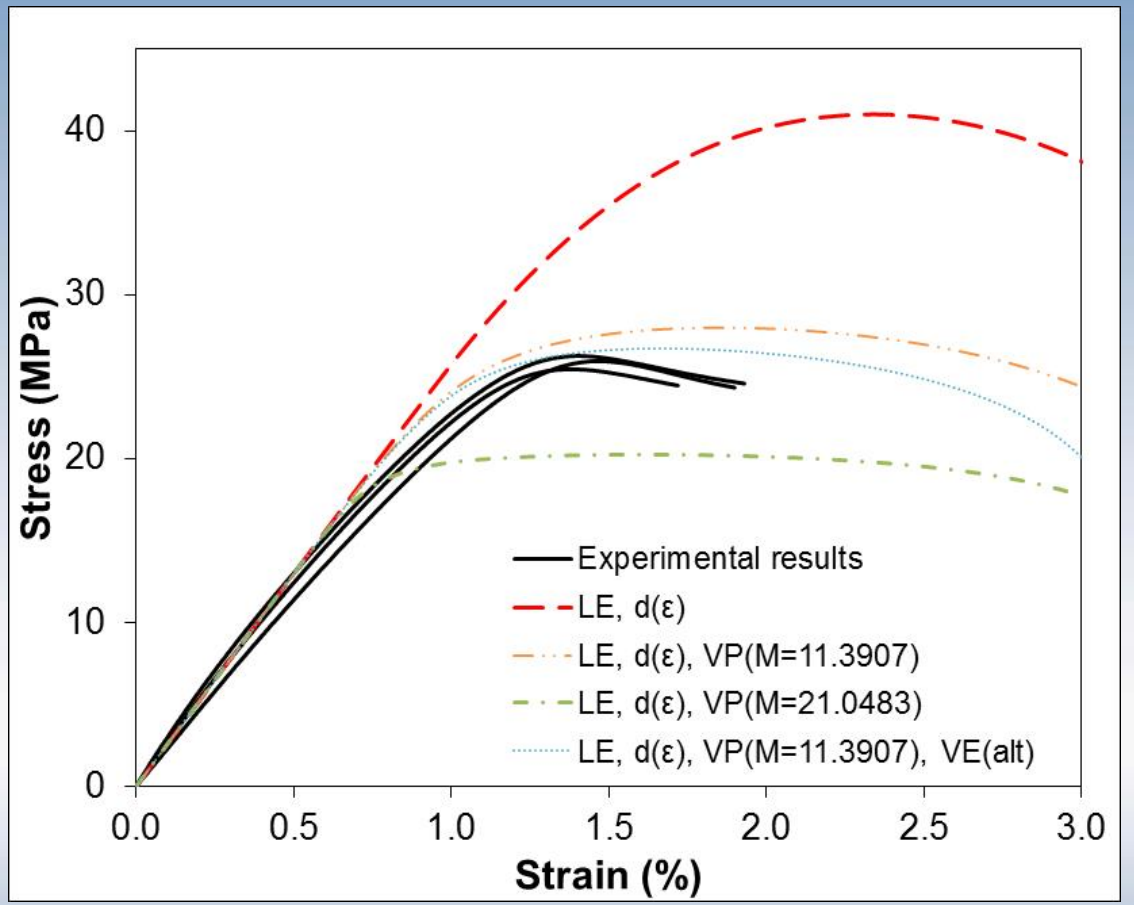
- Simulation of stress-strain curves



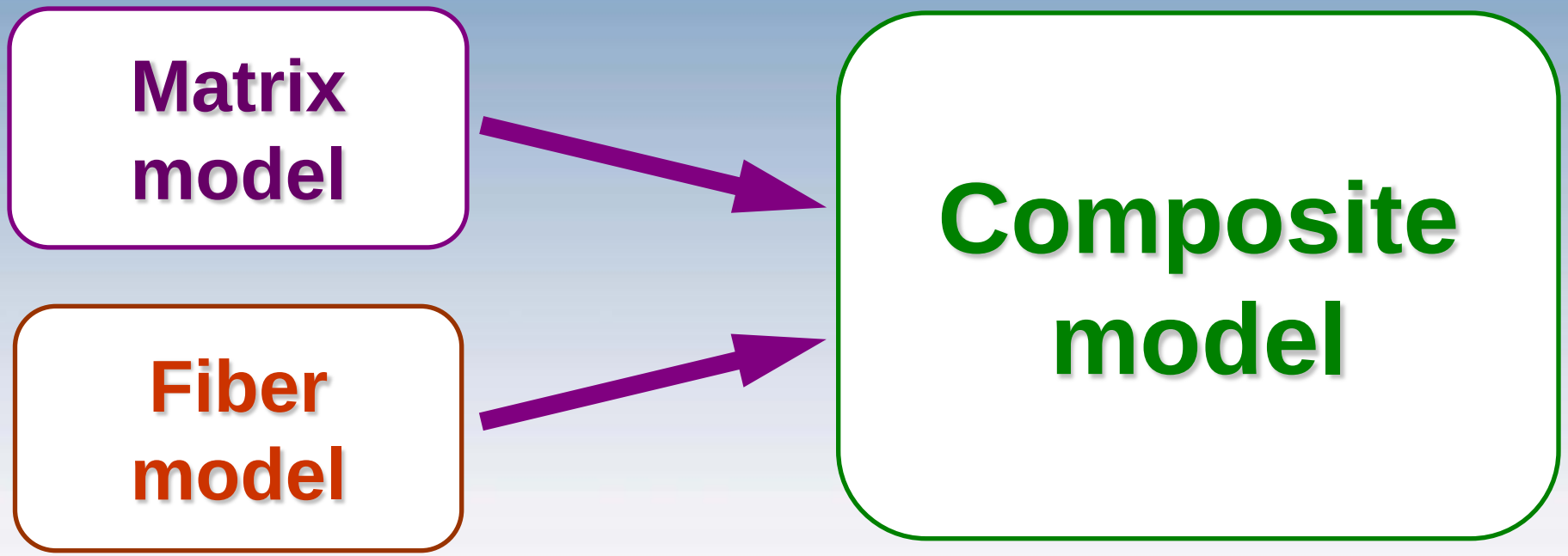
Material model: inverted incremental model







Material model: Constitutive model



- For example: $\sigma_c = \sigma_f V_f + \sigma_m V_m$

Application

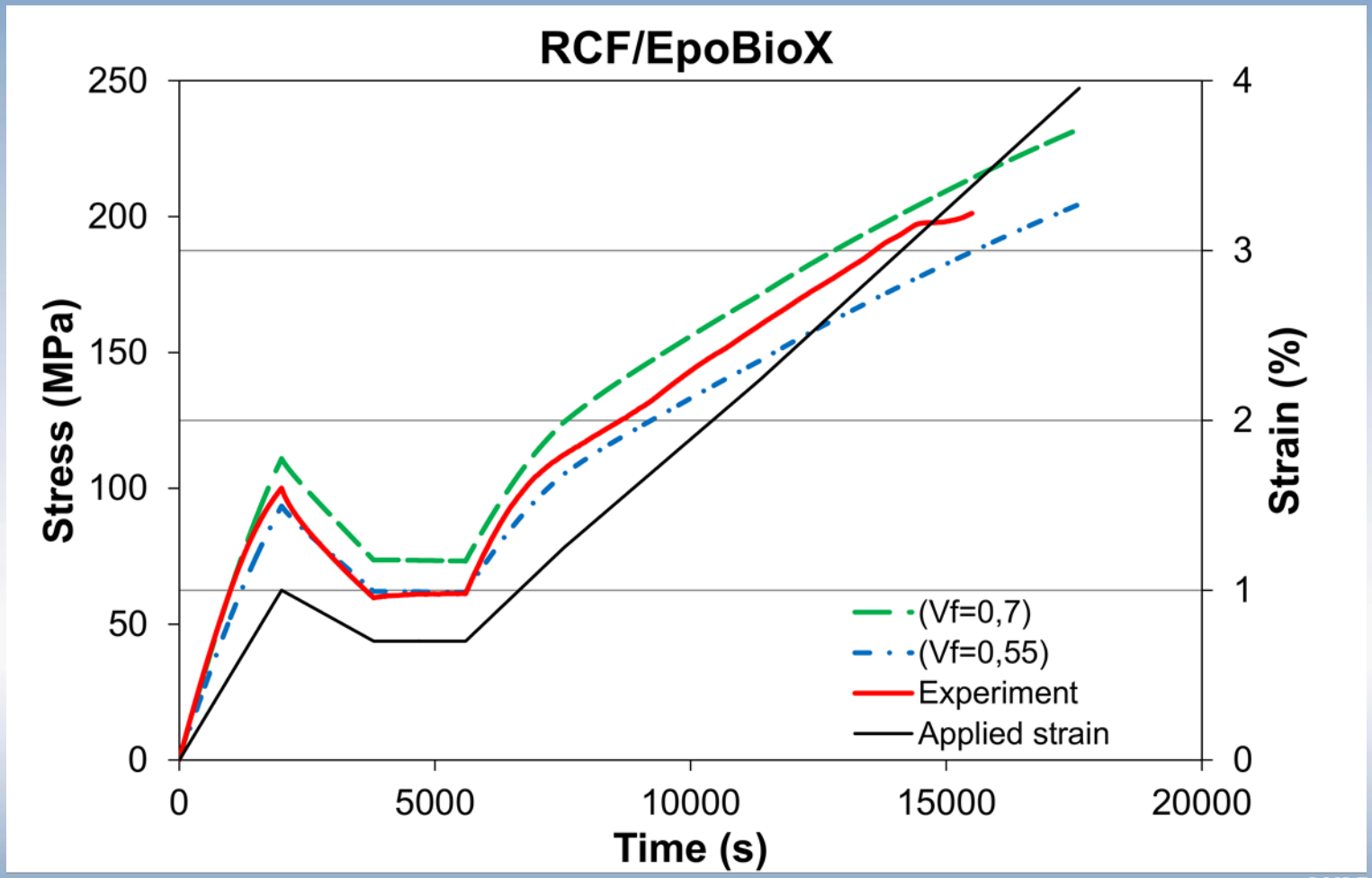
EpoBioX resin

- Negligible viscoplasticity
- Viscoelasticity was characterized from experimental relaxation tests

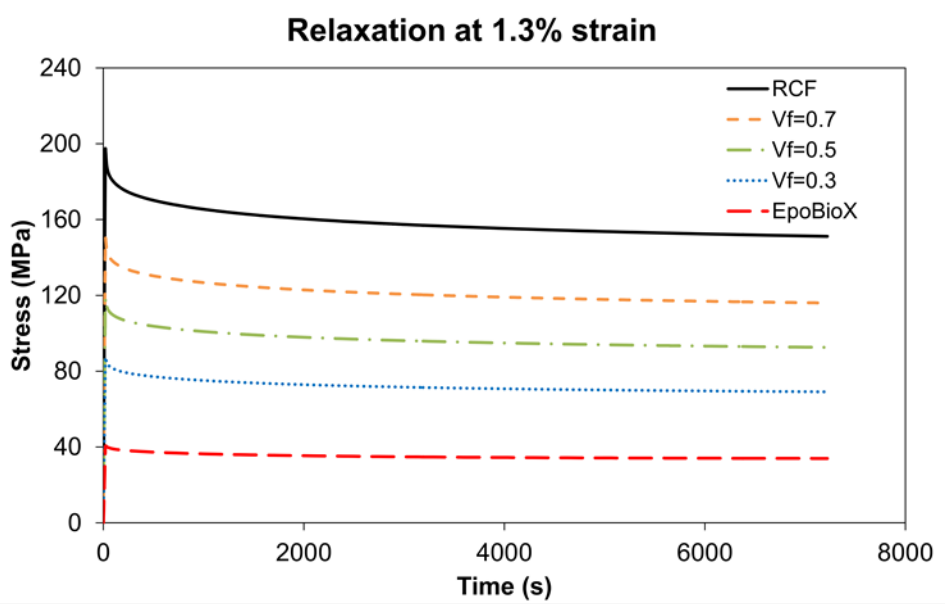
Regenerated cellulose fibers

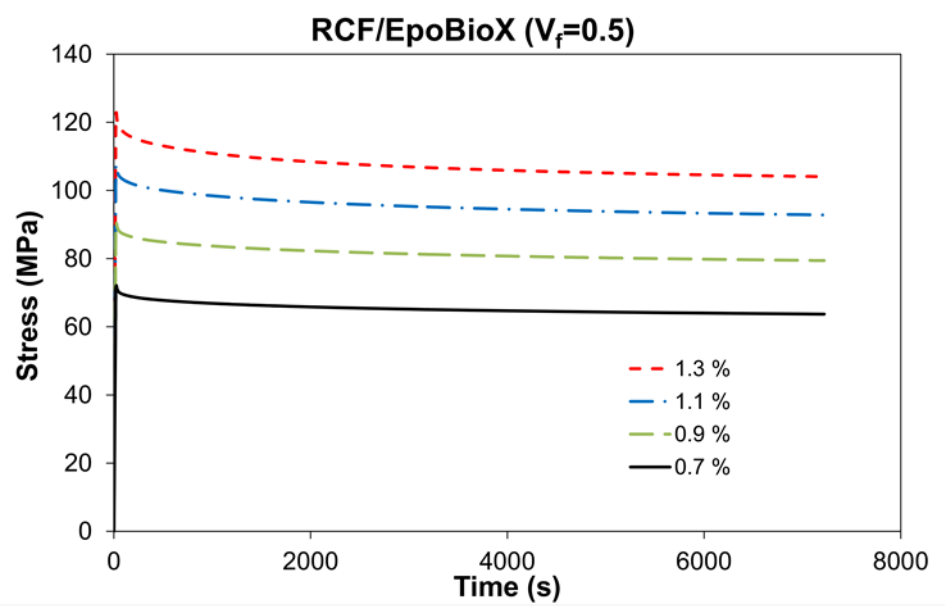
- High viscoplastic strains;
- Viscoleasitcity was characterized from simulated relaxation tests

Results


RCF/EpoBioX
Stress (MPa)
Strain (%)
Time (s)
0
50
100
150
200
250
0
1
2
3
4
0
5000
10000
15000
20000
(Vf=0,7)
(Vf=0,55)
Experiment
Applied strain

Results


Relaxation at 1.3% strain
Stress (MPa)
Time (s)
RCF
Vf=0.7
Vf=0.5
Vf=0.3
EpoBioX
0
40
80
120
160
200
240
0
2000
4000
6000
8000


RCF/EpoBioX (Vf=0.5)
Stress (MPa)
Time (s)
1.3 %
1.1 %
0.9 %
0.7 %
0
20
40
60
80
100
120
140
0
2000
4000
6000
8000

Summary

- It has been demonstrated that combination of existing models for non-linear viscoelasticity (Schapery), Viscoplasticity (Zapa) and damage (Varna) can be successfully used to simulate stress controlled tests.
- Two alternative formulations of non-linear viscoelastic model in terms of stresses or strains can be used, however they can not be exactly inverted, instead numerical procedure should be employed.
- Inverted incremental model can be used to simulate relaxation tests to obtain viscoleasticity in strain formulation.
- Constitutive modeling showed good agreement with experiment. This model can be further used to simulate pure viscoelastic relaxation tests for composite and from these simulations viscoleastic parameters for composite can be obtained.

Acknowledgments

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- Swerea SICOMP is acknowledged for help with manufacturing of materials

Thank you for your attention!