Glass Performance Days 2025

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GLASS PERFORMANCE DAYS 2025

Multi-Material Polymeric Interlayers

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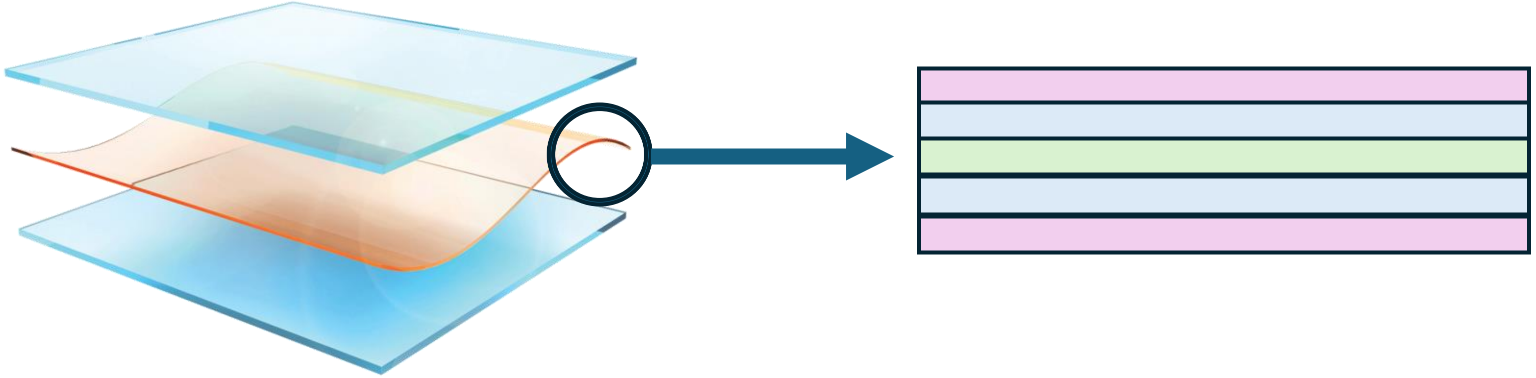
Multi-Material Polymeric Interlayer



Interlayer composed of different materials

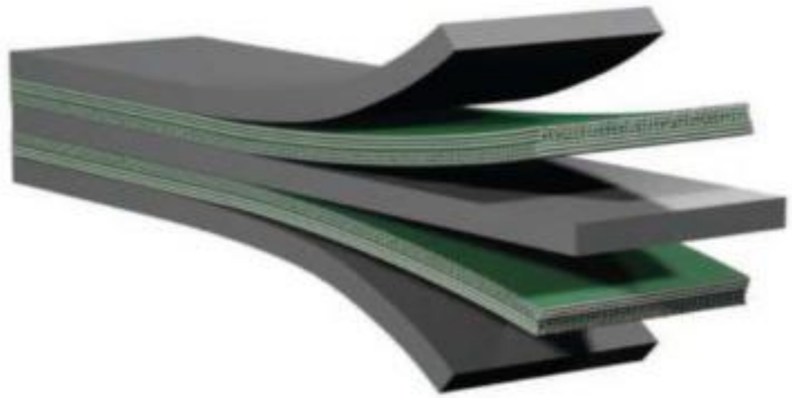
Enhances some characteristic of the full stack:

✓ Acoustic insulation performance -> Damping
✓ Optical transmissivity
✓ Mechanical strength
✓ Electrical connectivity (PDLC)

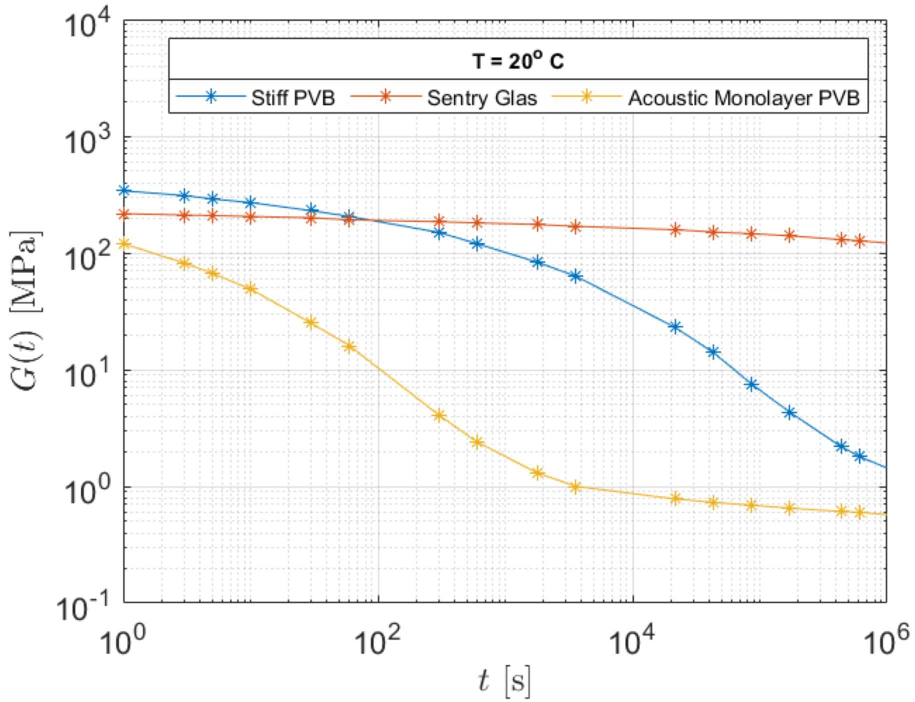
Multi-Material Polymeric Interlayer

Each material has its own:

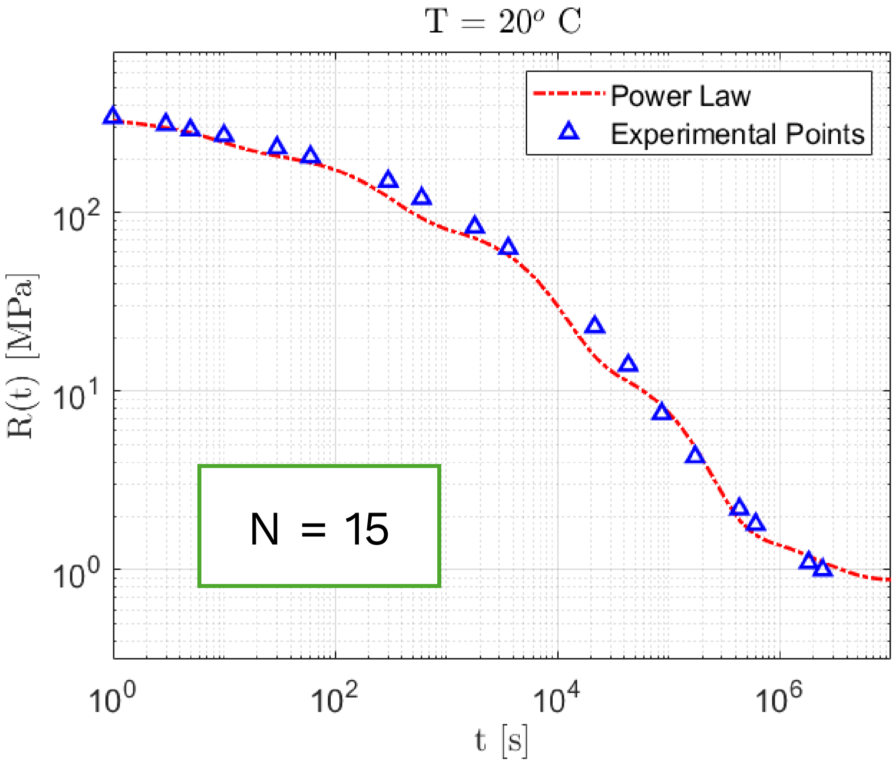
- **Relaxation function**
- **Thickness**



Difficulty in modelling mechanical properties of the laminated package



Relaxation function of the polymeric interlayer:
Prony Series *approximation*



$$R(t) = R_0 + \sum_{i=1}^{N} R_i e^{-t/\vartheta_i}$$

where:

R_i : i-th relaxation shear modulus

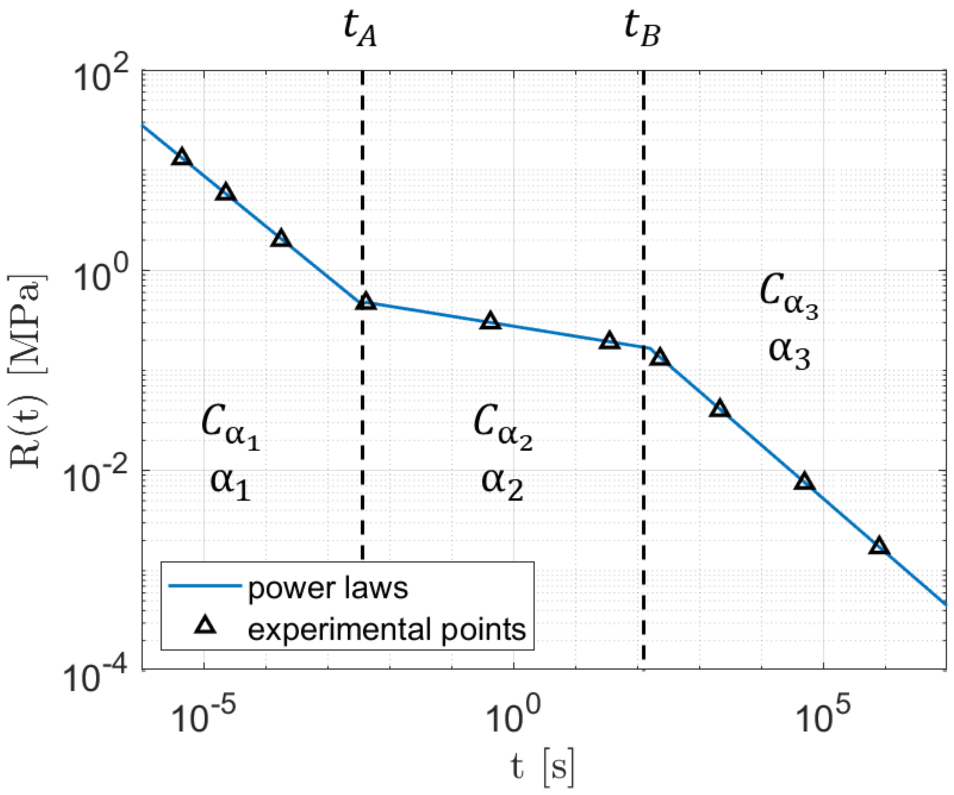
ϑ_i : corresponding relaxation time.

R_0 : material stifness at t=0.

- G(t) is described by a **Prony series**
- An algorithm is necessary to calibrate the parameters
- Calibration not straightforward

Relaxation function of the polymeric interlayer:
Power law *approximation*

$$G(t) = \frac{C_\alpha}{\Gamma(1-\alpha)} t^{-\alpha}$$

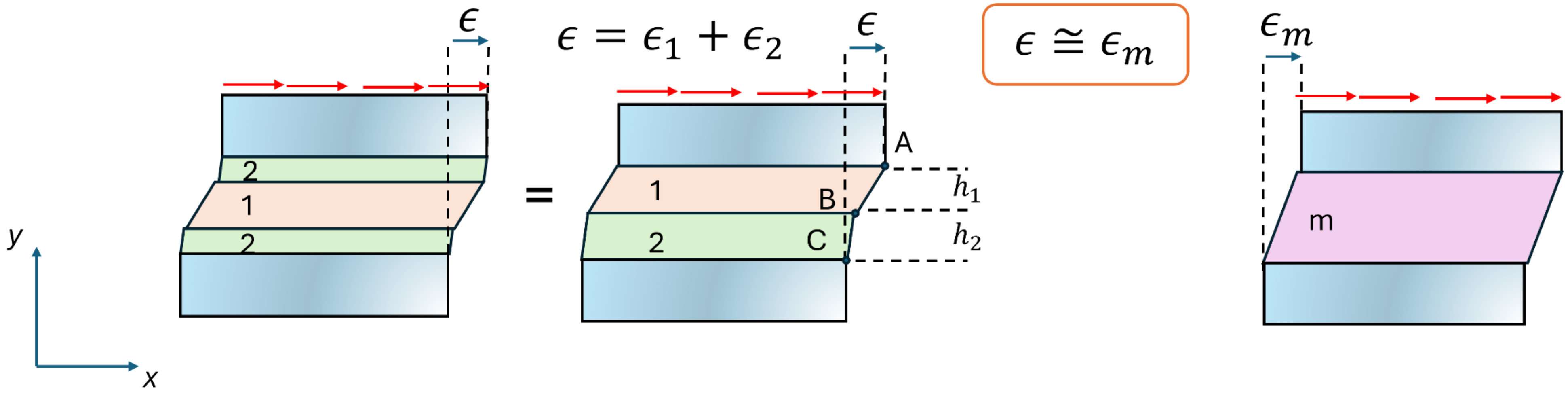


- In the bi-log plot they are **lines**
- $\boldsymbol{\alpha}$ the slope of the line, with $0 < \alpha < 1$
- $\boldsymbol{C_\alpha}$ $[MPa\ s^\alpha]$ is the stiffness value at $t = 1\ s$.

✓ The whole G(t) can be approximated by connected branches of **power laws**
✓ Geometric interpretation of the parameters
✓ Straightforward calibration

The model

- Simplest case: pure shear applied to the stack,
- The total deformation is the sum of the deformations of the interlayer materials,
- One can calculate the total relaxation function once the relaxation function of the various interlayer materials is known.



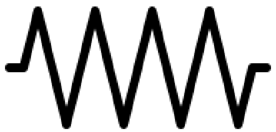
The model scheme

- **In elastic solids**: stress is proportional to the **zero-order derivative** of strain.

- **In liquids**: stress is proportional to the **first derivative** of strain.

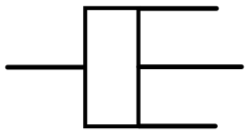
- **Viscoelastic materials**: stress is proportional to a real-order derivative, **intermediate between 0 and 1** of the strain over time.

Spring



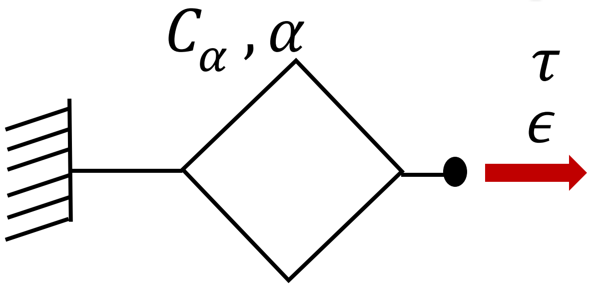
$$\tau(z,t) = K[\epsilon(z,t)]$$

Dashpot



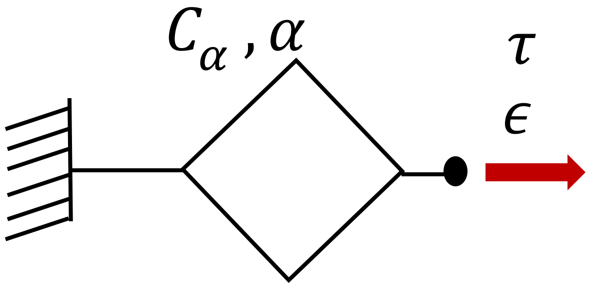
$$\tau(z,t) = \mu \frac{\delta}{\delta t}[\epsilon(z,t)]$$

Spring Pot



$$\tau(z,t) = C_\alpha \, {}_0^C D_t^\alpha [\epsilon(z,t)]$$

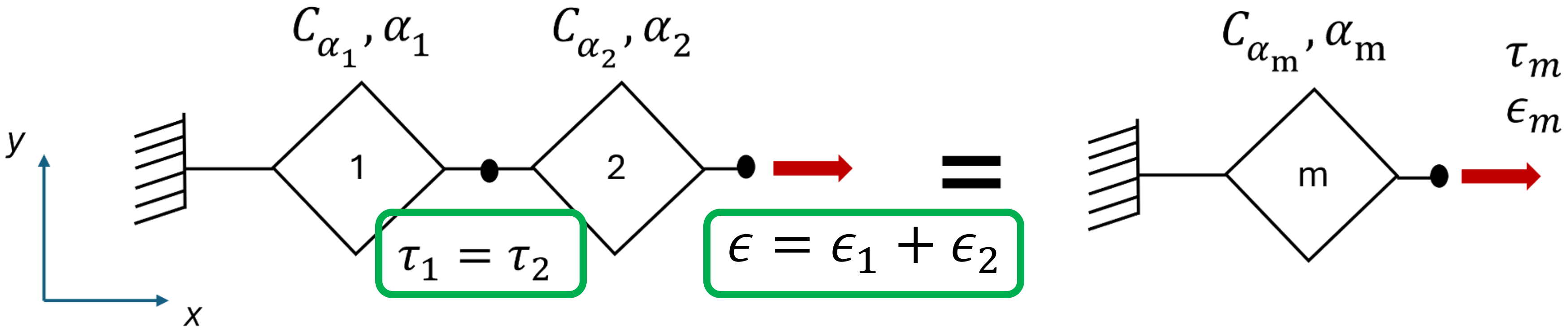
The model scheme



$$\tau(z,t) = C_\alpha\, {}_0^C D_t^\alpha[\epsilon(z,t)]$$

Laminated package with MMPI is modeled with **Spring-Pots in series**:

- the total displacement is the **sum** of the **element displacements,**
- **Same stress** in every element

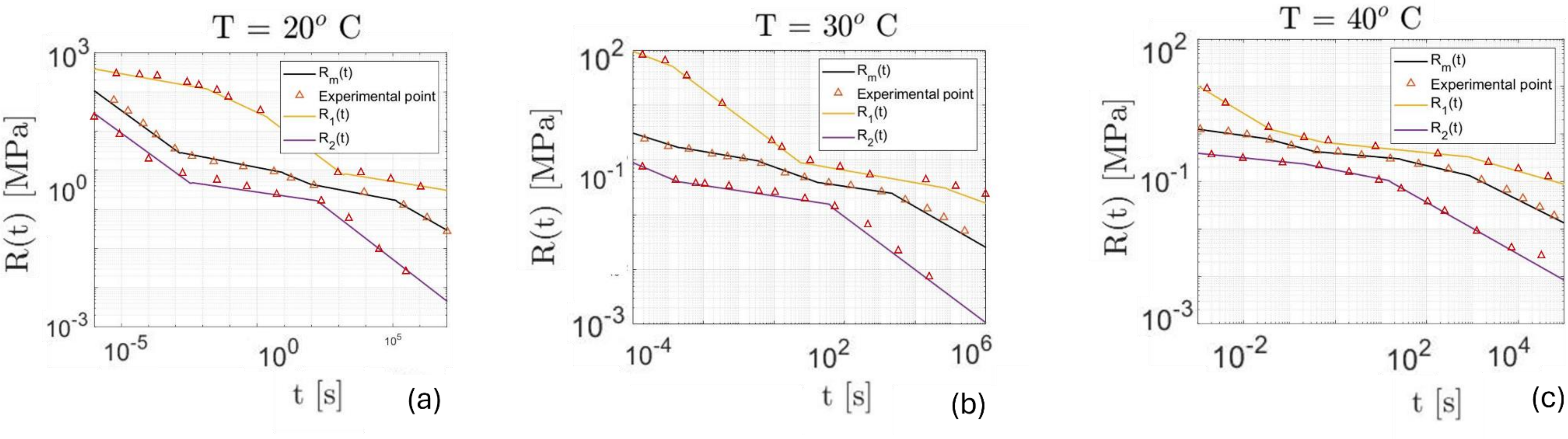


Relaxation functions from DMTA (Dynamic Thermal Material Analyzer)

$\boldsymbol{R_1}$ = Stiff PVB

$\boldsymbol{R_2}$ = Acoustic Monolayer PVB (Trosifol Sound Control Monolayer)

$\boldsymbol{R_m}$ = Combination of the two materials



The FE model

FEM model

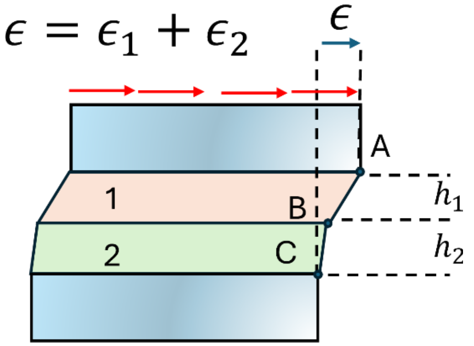
From the Relaxation Functions of DTMA:

1) Outer Layer

2) Inner Layer

Calculate the total deformation ϵ

$$\epsilon = \epsilon_1 + \epsilon_2$$



Calculate the total shear stress τ

By reversing the constitutive equation of the polymeric

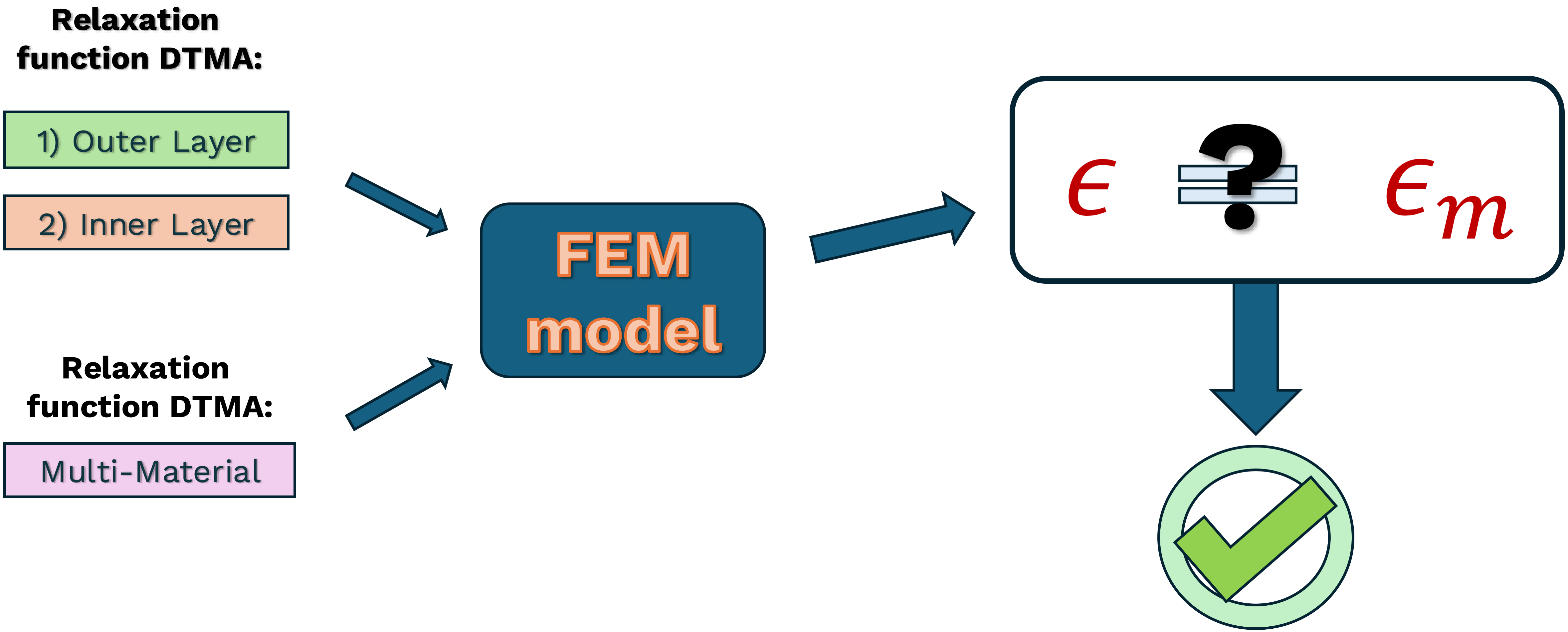
$$\tau(z,t) = \tau(z,0)R(t) + \int_0^t \frac{\partial \epsilon}{\partial \bar{t}} R(t-\bar{t})d\bar{t}$$

FULL VISCOELASTIC ANALYSIS

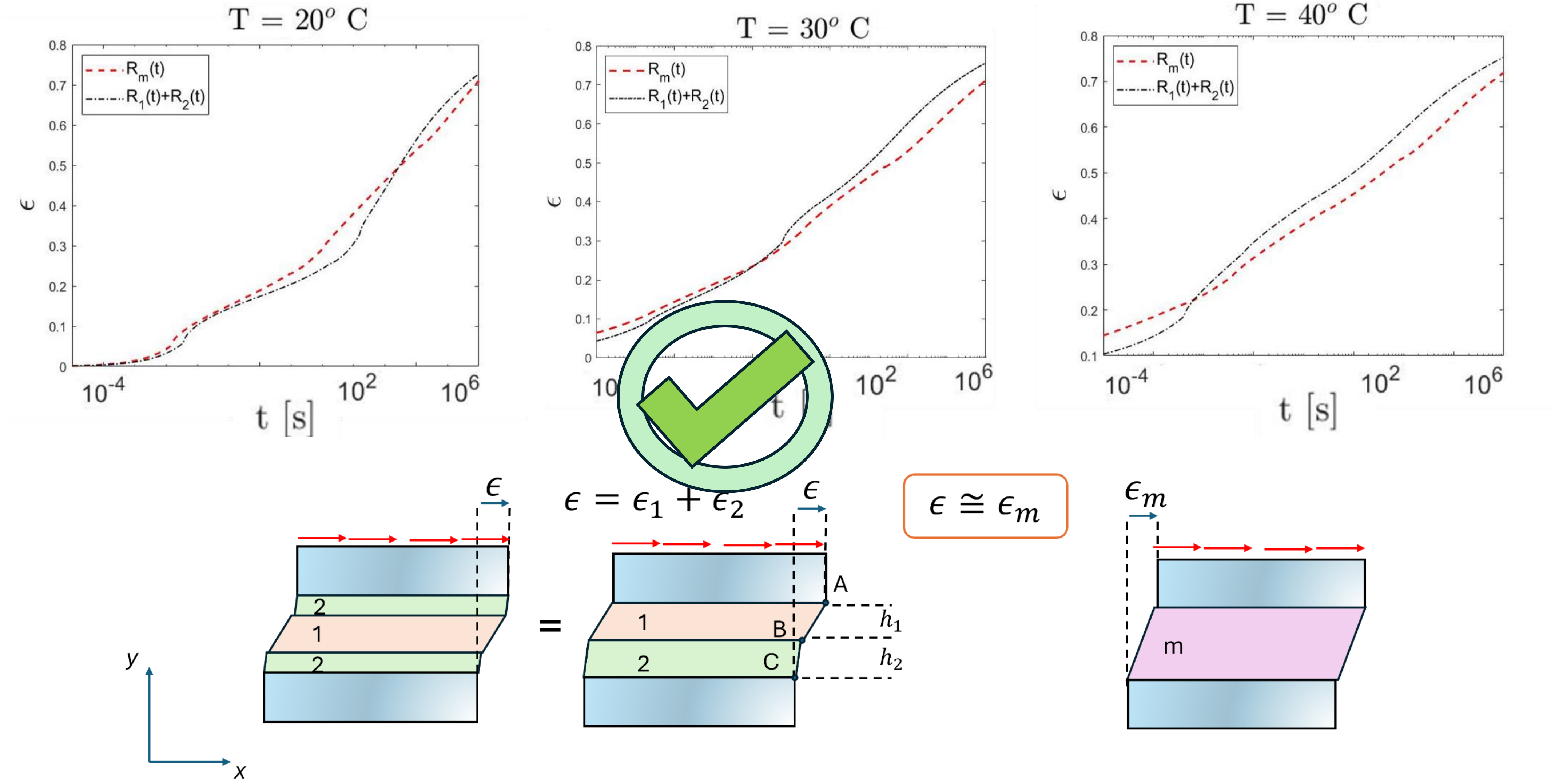
Calculate the Relaxation function of the Multilayer

$$R(t)$$

Concept of the model



Model Results: Deformation Comparison



Concept of the model

Relaxation function DTMA:

2) Outer Layer

1) Inner Layer

FEM model

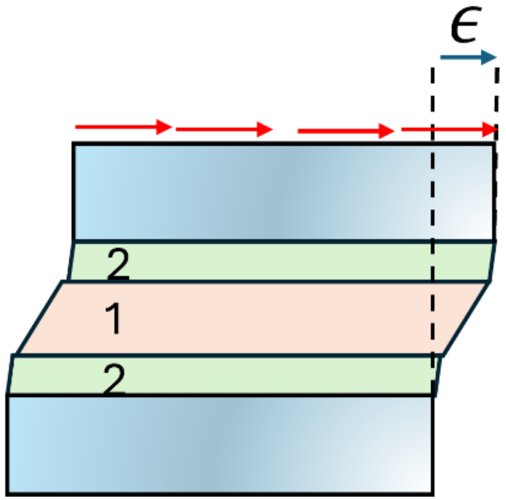
Simulated

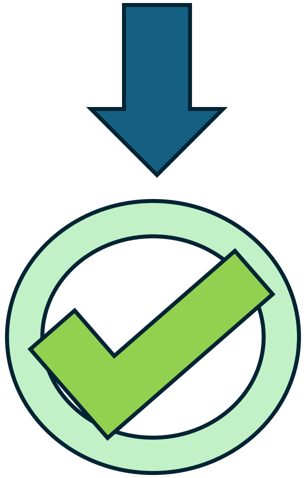
Multi-Material

?

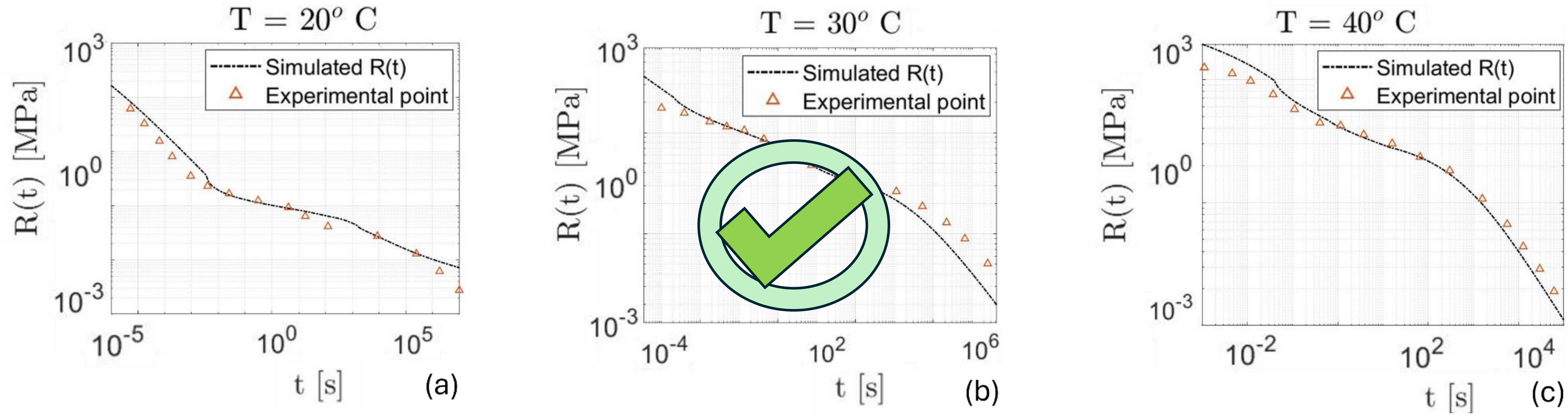
Relaxation function DTMA:

Multi-Material





Model Results: Simulated vs Experimental Relaxation Function

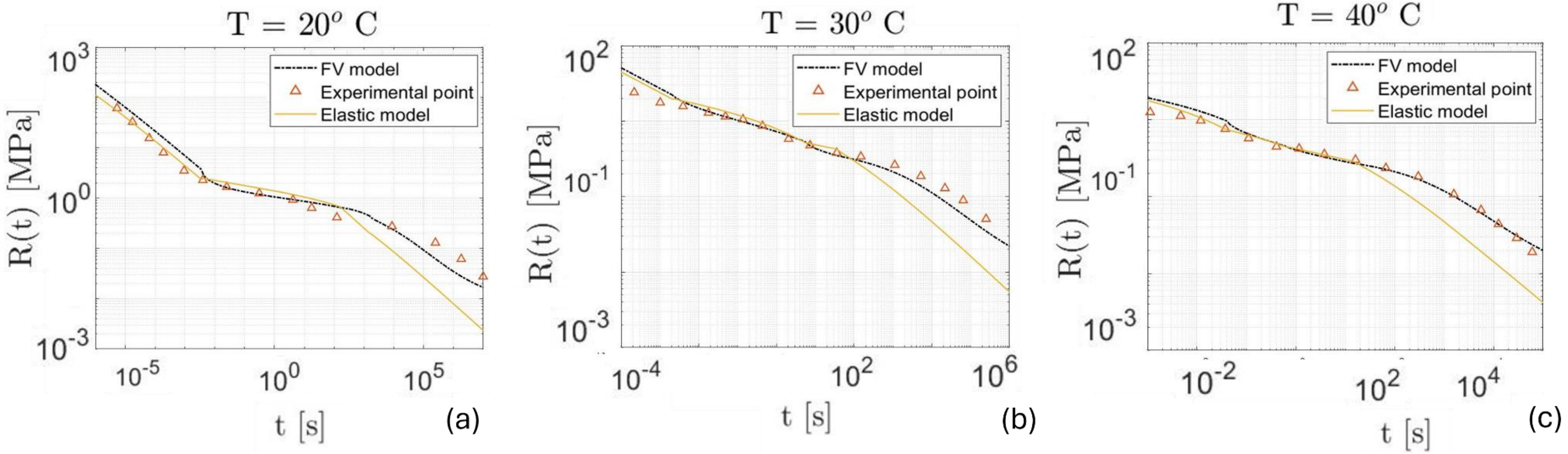


Model Results: Comparison with Elastic Model

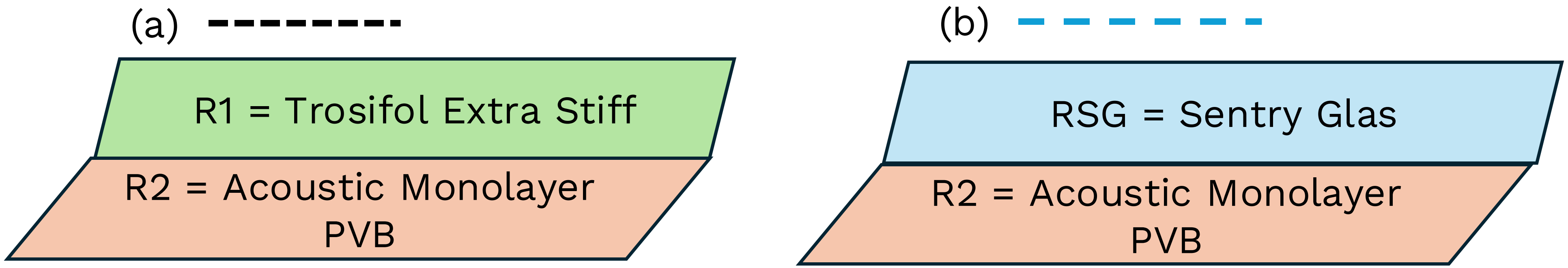
Elastic Model

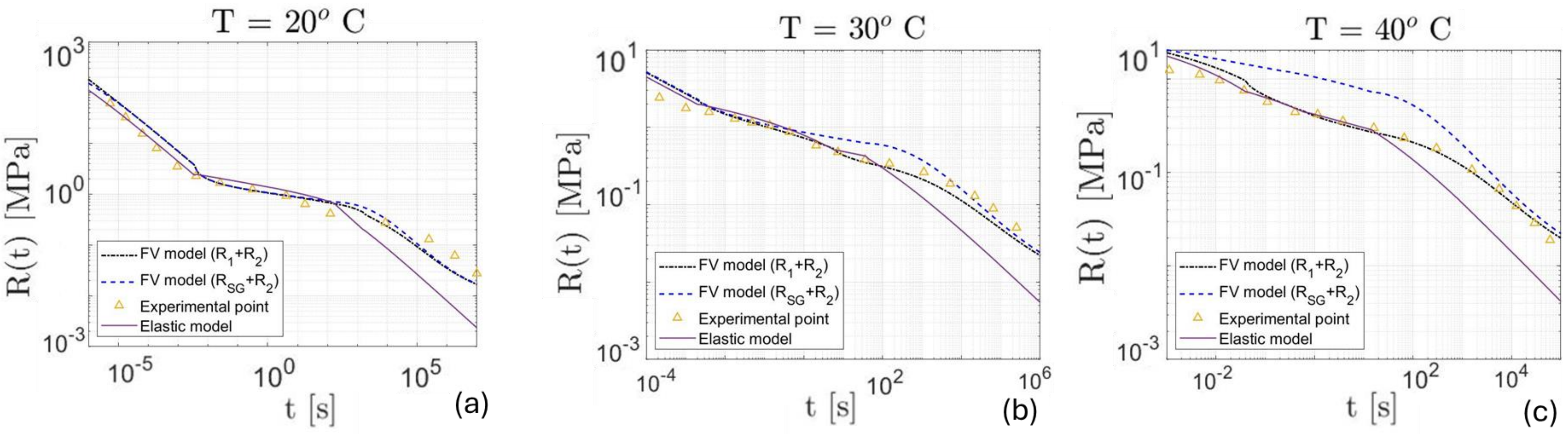
$$\frac{h_1+h_2}{R_m(t)} = \frac{h_1}{R_1(t)} + \frac{h_2}{R_2(t)}.$$

Miriam Schuster · Michael Härth · Kerstin Thiele · Stephen J. Bennison. "*Quantification of the linear viscoelastic behaviour of multilayer polymer interlayers for laminated glass*"



Optimization: Sentry Glas vs Trosifol Extra Stiff PRO





Conclusion

Methodology Validation

- Successfully applied power law interpolation to experimental relaxation data from DMTA analysis
- Implemented fractional derivatives to accurately characterize viscoelastic behavior

Model Performance

- The viscoelastic model demonstrates excellent agreement with experimental data
- Elastic models prove inadequate for reliable predictions

Practical Applications

- Method is generalizable to various MMPI configurations (different polymers, thicknesses)
- Enables predictive design of novel MMPI architectures

Industrial Relevance

- Provides reliable, interpretable mechanical response solutions

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Thank You

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