Mastering Viscoelasticity of Pressure Sensitive Tapes in Engineered Assemblies

Felix Foerster and Paul Ludwig Geiß
University of Kaiserslautern (Germany)

Pressure sensitive tapes in engineering applications

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How can you convince an engineer?

Explaining the benefits of viscoelasticity

„John the bear“: (BBC, 1985)

Source: YouTube

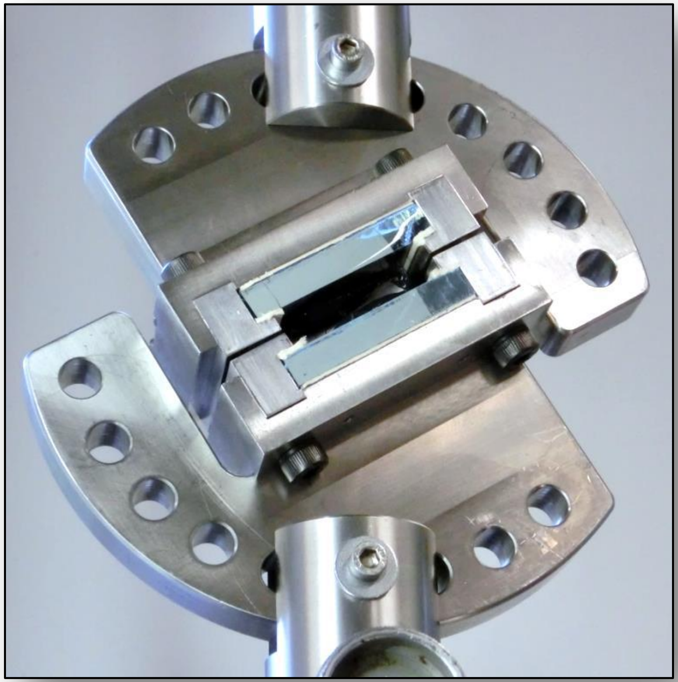
Explaning the benefits of viscoelasticity

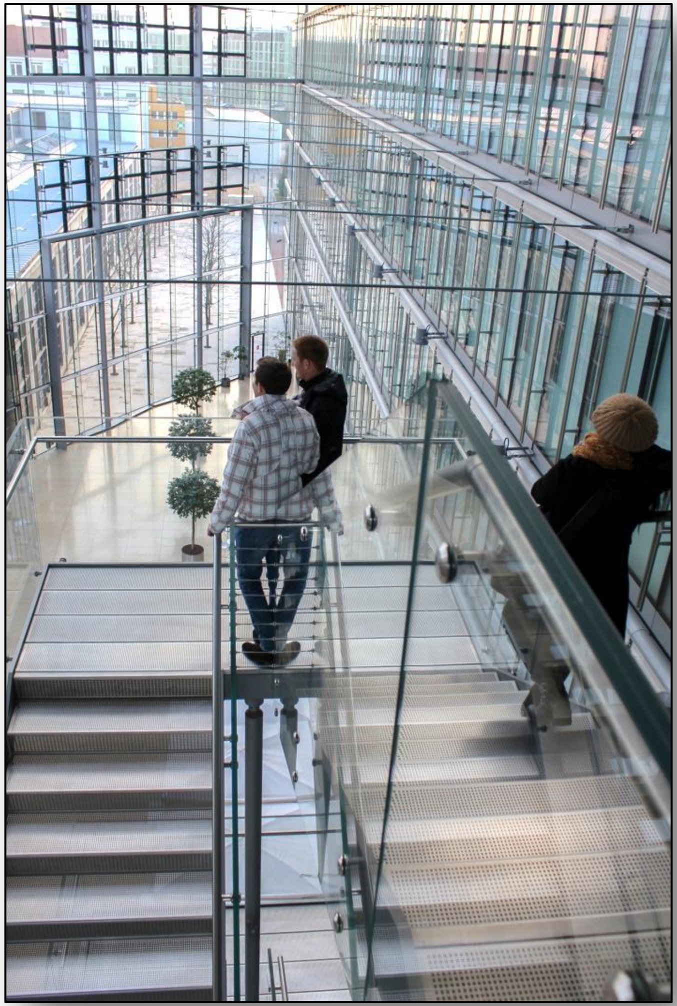
The Slammer: (2009)

Source: YouTube

Goal

- Engineering data and design limits of joints with pressure sensitive adhesives?

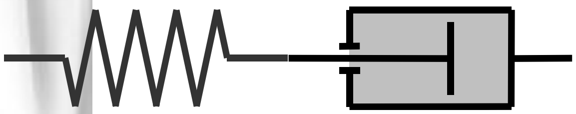




Source: Wikipedia

Terminology – linear elasticity

- In the 17th century, the British physicist Robert Hooke* defined the basic relation between stress and strain as "ut tensio, sic vis".
- The fundamental "linearizing" assumptions of linear elasticity are:
  - infinitesimal small strains or "small" deformations
  - linear relationships between the components of stress and strain
  - In the linear elastic region, constitutive material models are able to correlate strain to stress without the need to consider the history of stress and strain events a specific object or assembly has been subjected to.

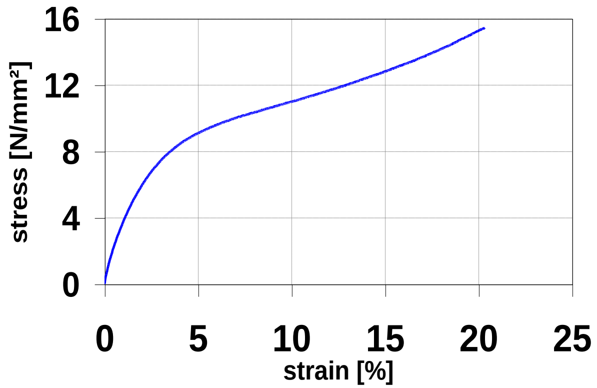


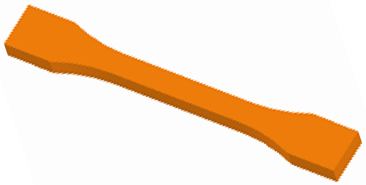
Terminology – linear viscoelasticity

- When a viscoelastic material is subjected to stress, instantaneous elastic strain takes place followed by delayed elastic strain.
- Following delayed elastic strain, viscous flow can often be observed for adhesives with low crosslinking density.
- In linear viscoelasticity, the creep and the relaxation function are interrelated and each would permit the derivation of the viscoelastic constitutive relation.

Terminology – non-linear viscoelasticity

- In practice, polymers and adhesive joints are often being used under service conditions exceeding the limitations of linear viscoelasticity.
- Indications for non-linear viscoelastic properties include changes of creep compliance for different stress levels and that the mechanical behavior depends on the sequence in which previous mechanical incidents have occurred.

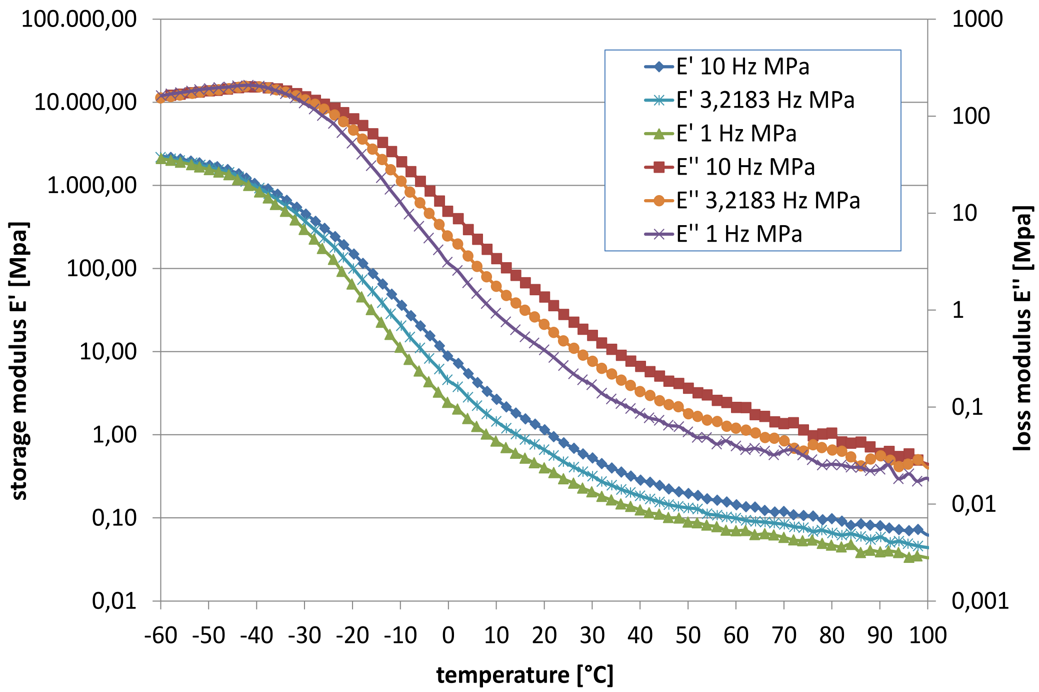




Practical applications - linear viscoelastic DMTA

- Results of DMTA-experiments using bulk specimen:
  - Storage modulus, loss modulus, tangent δ

courtesy of GABO QUALIMETER



Theoretical background of DMTA

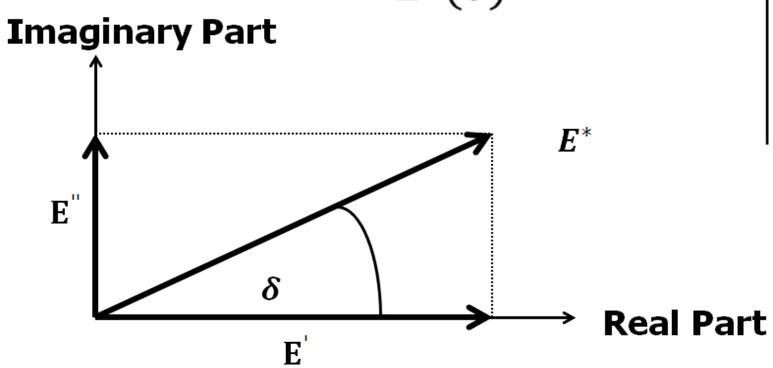
- Input: Stress $\sigma(t) = \sin(\omega t)$
- Output: Strain $\varepsilon(t) = \sin(\omega t + \delta)$

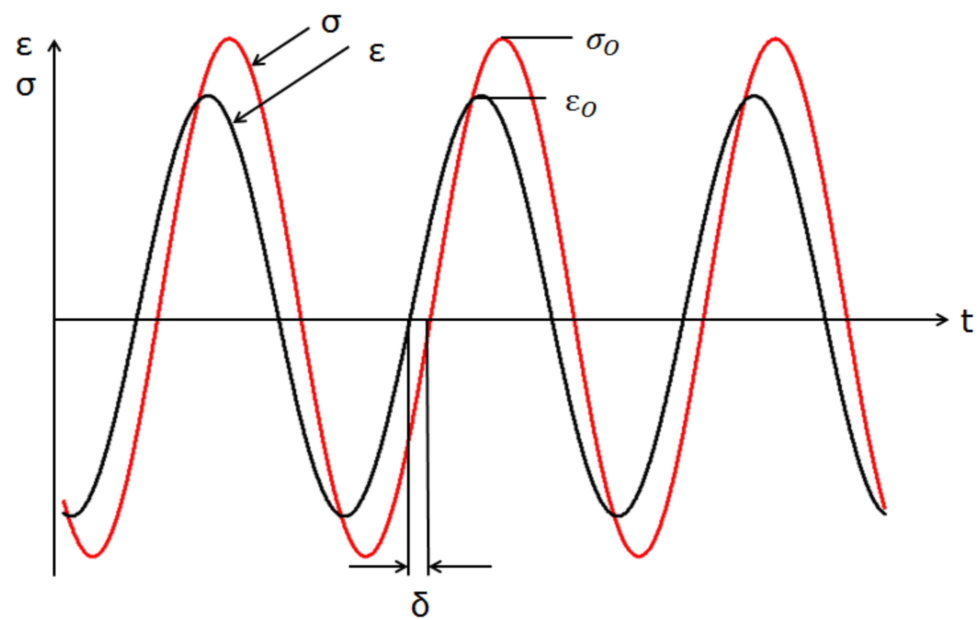
$$|E^*| = \sqrt{[E'(\delta)]^2 + [E''(\delta)]^2}$$

$$E'(\delta) = |E^*| \times \cos(\delta)$$

$$E''(\delta) = |E^*| \times \sin(\delta)$$

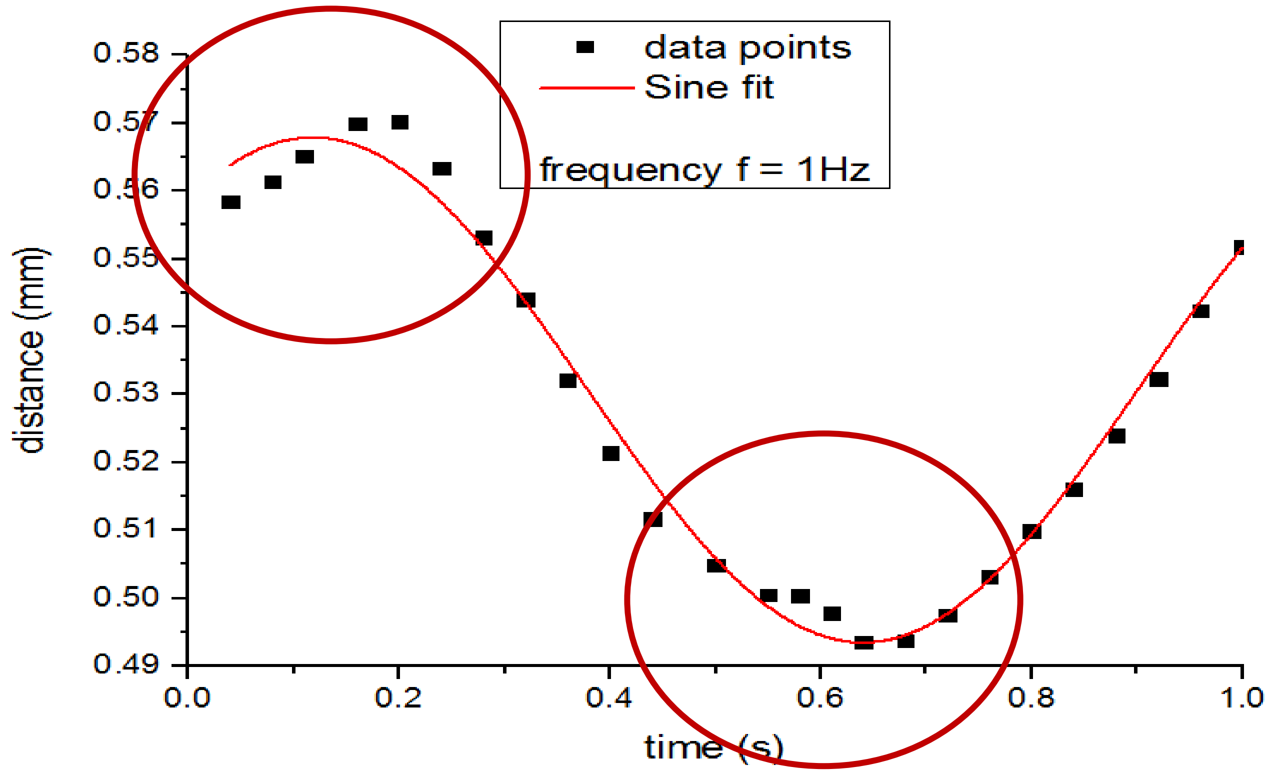
$$\tan\delta = \frac{E''(\delta)}{E'(\delta)}$$





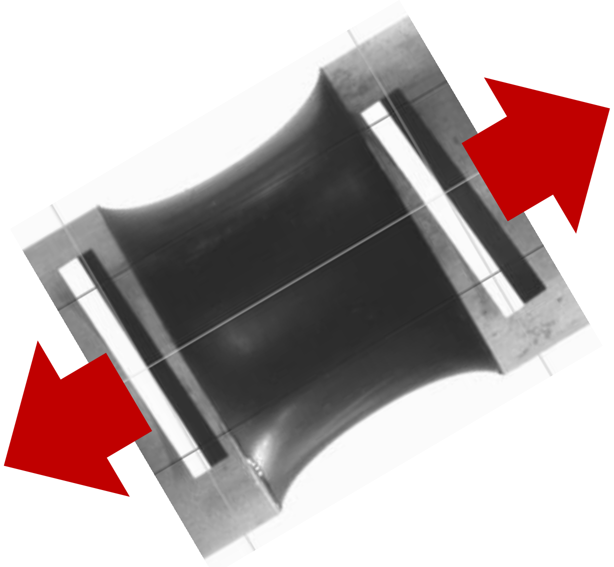
Issues related to linear viscoelastic DMTA

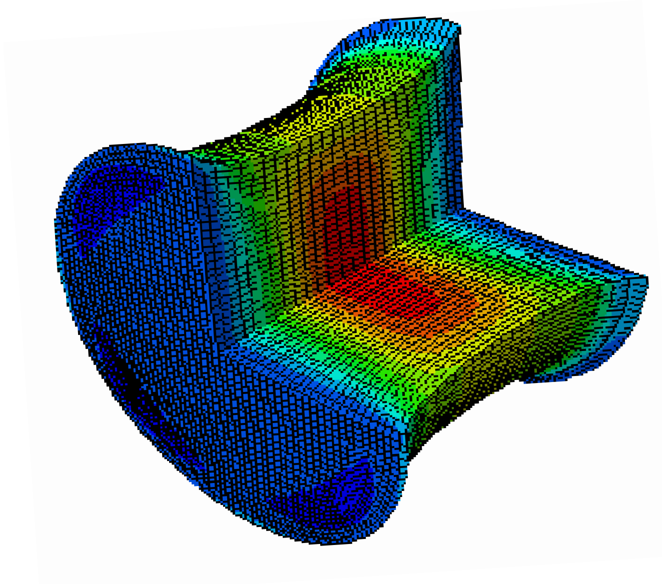
- Caution should be exercised to avoid violation of the limits of linear viscoelasticity



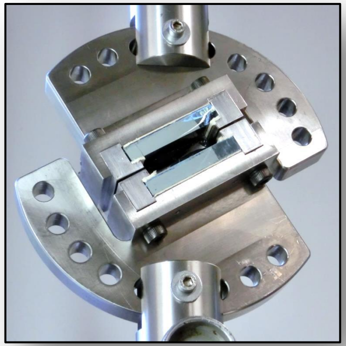
Issues related to linear viscoelastic DMTA

- Reason for deviation from linear viscoelasticity:
  - Strain-induced non-isotropic material properties
  - Non-uniform stress field due to interfacial constrains

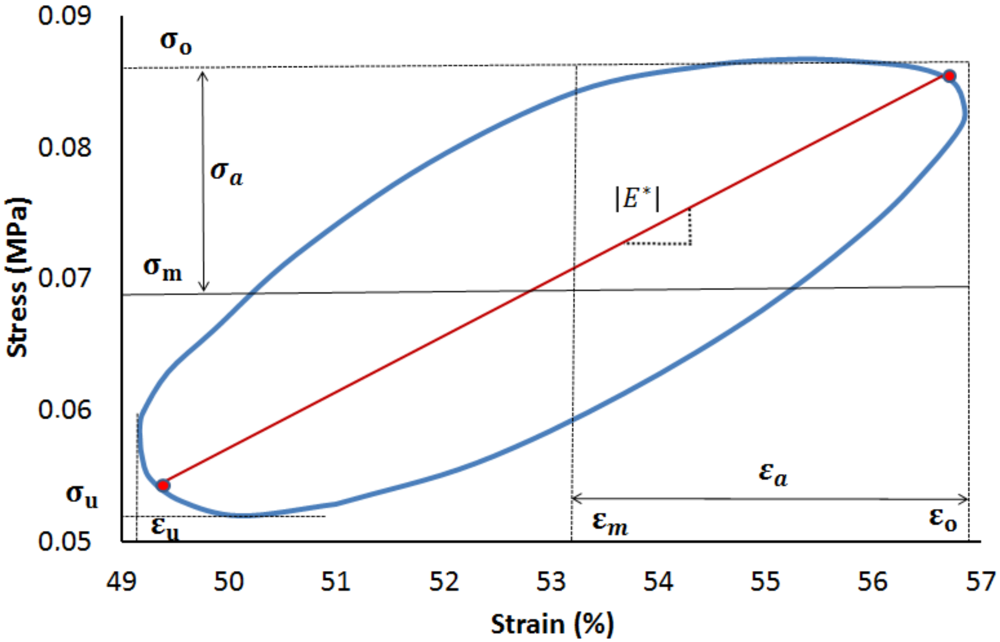


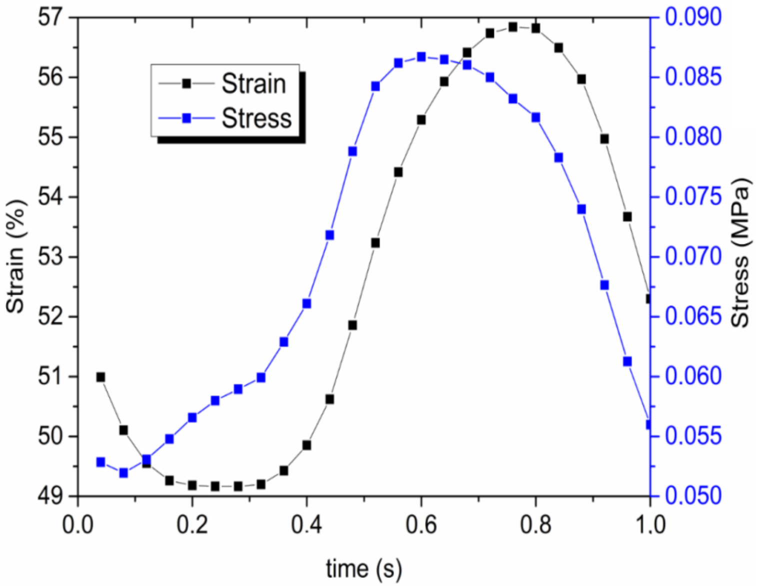


Non-linear viscoelastic analysis



- The concept of hysteresis analysis





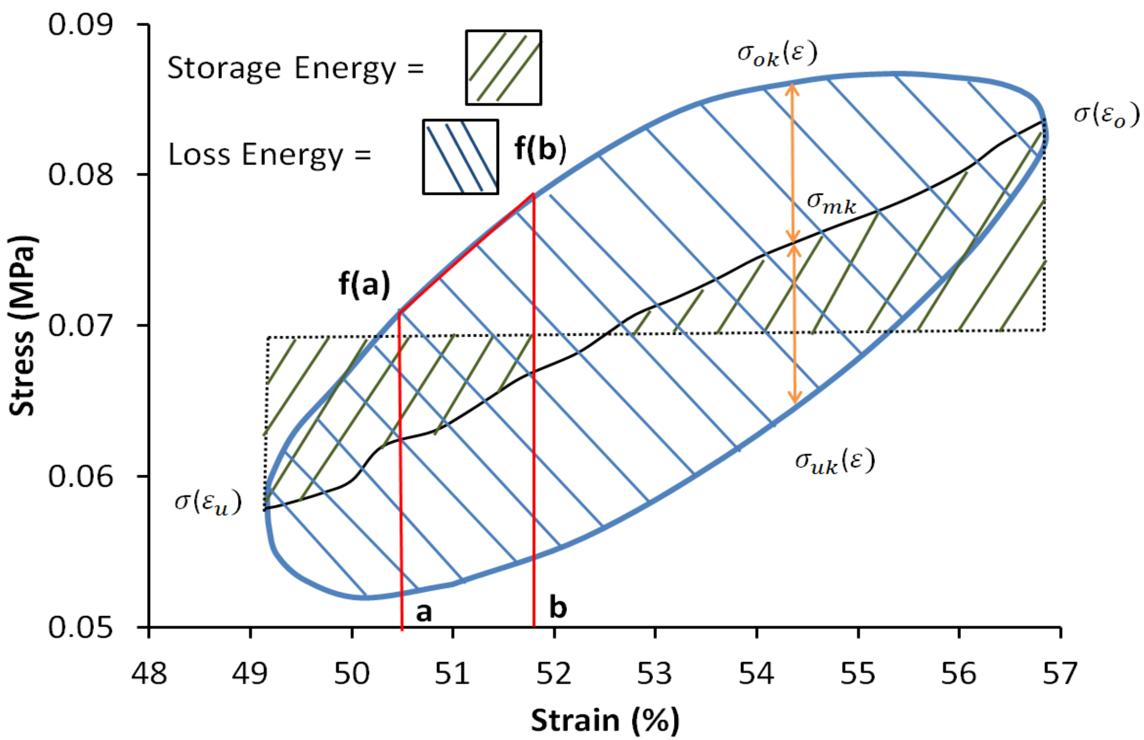
Characteristic features of a hysteresis loop:

- σ_o = maximum stress
- σ_m = mean load
- σ_u = minimum stress
- σ_a = stress amplitude
- ε_o = maximum strain
- ε_m = mean strain
- ε_u = minimum strain
- ε_a = strain amplitude

Hysteresis features

- Storage energy and loss energy are calculated by integration

$$A = (b - a) \times \frac{f(a)+f(b)}{2}$$



Viscoelastic parameters

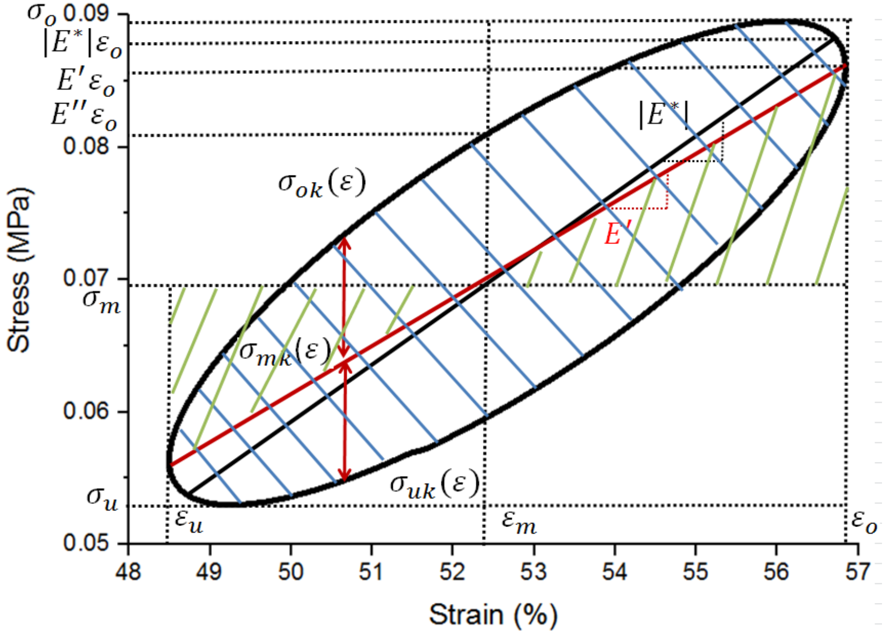
Loss- and storage energy:

$$W_L = \oint \sigma d\varepsilon = \pi \sigma_a \varepsilon_a \sin\delta$$

$$W_S = \int_{\varepsilon_u}^{\varepsilon_o} (\sigma_{mk} - \sigma_m) d\varepsilon = 2\left(\frac{1}{2}\sigma_a \varepsilon_a \cos\delta\right)$$

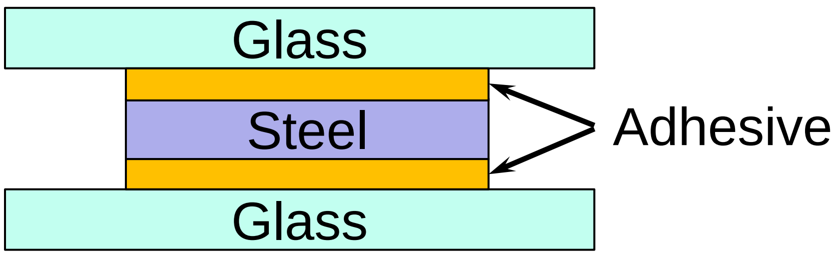
Lehr‘s damping ratio:

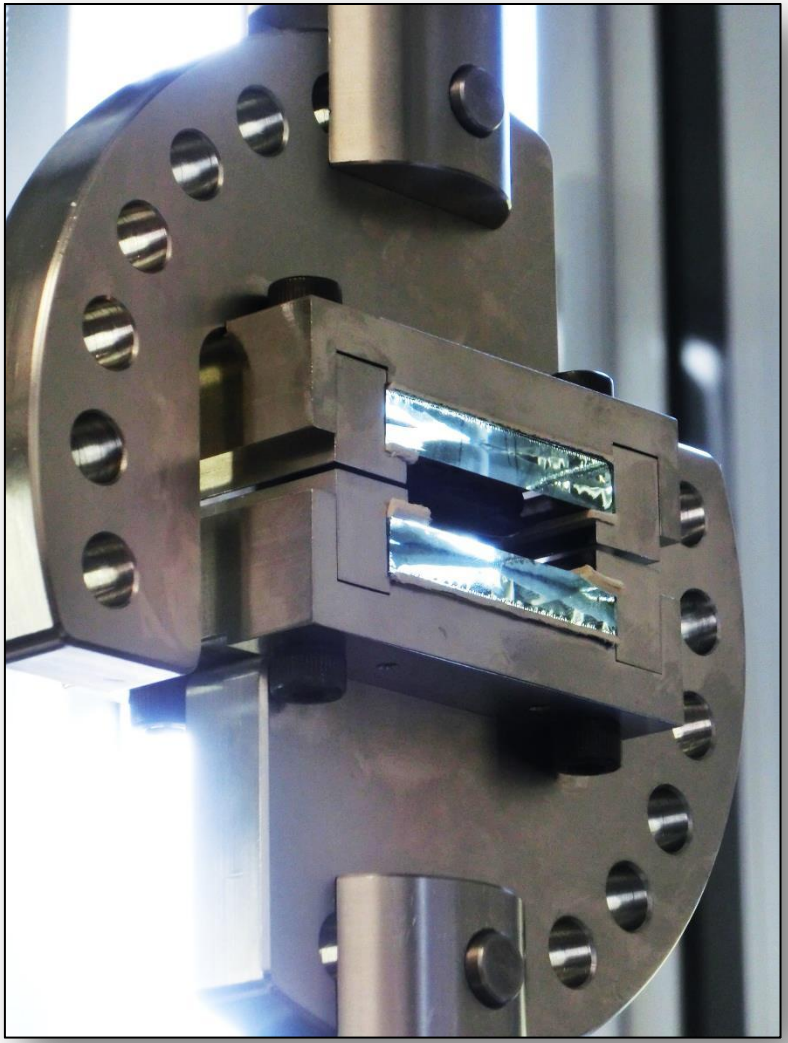
$$\Lambda = \frac{W_L}{W_S} = \frac{\pi \sigma_a \varepsilon_a \sin\delta}{\sigma_a \varepsilon_a \cos\delta}$$



Experimental

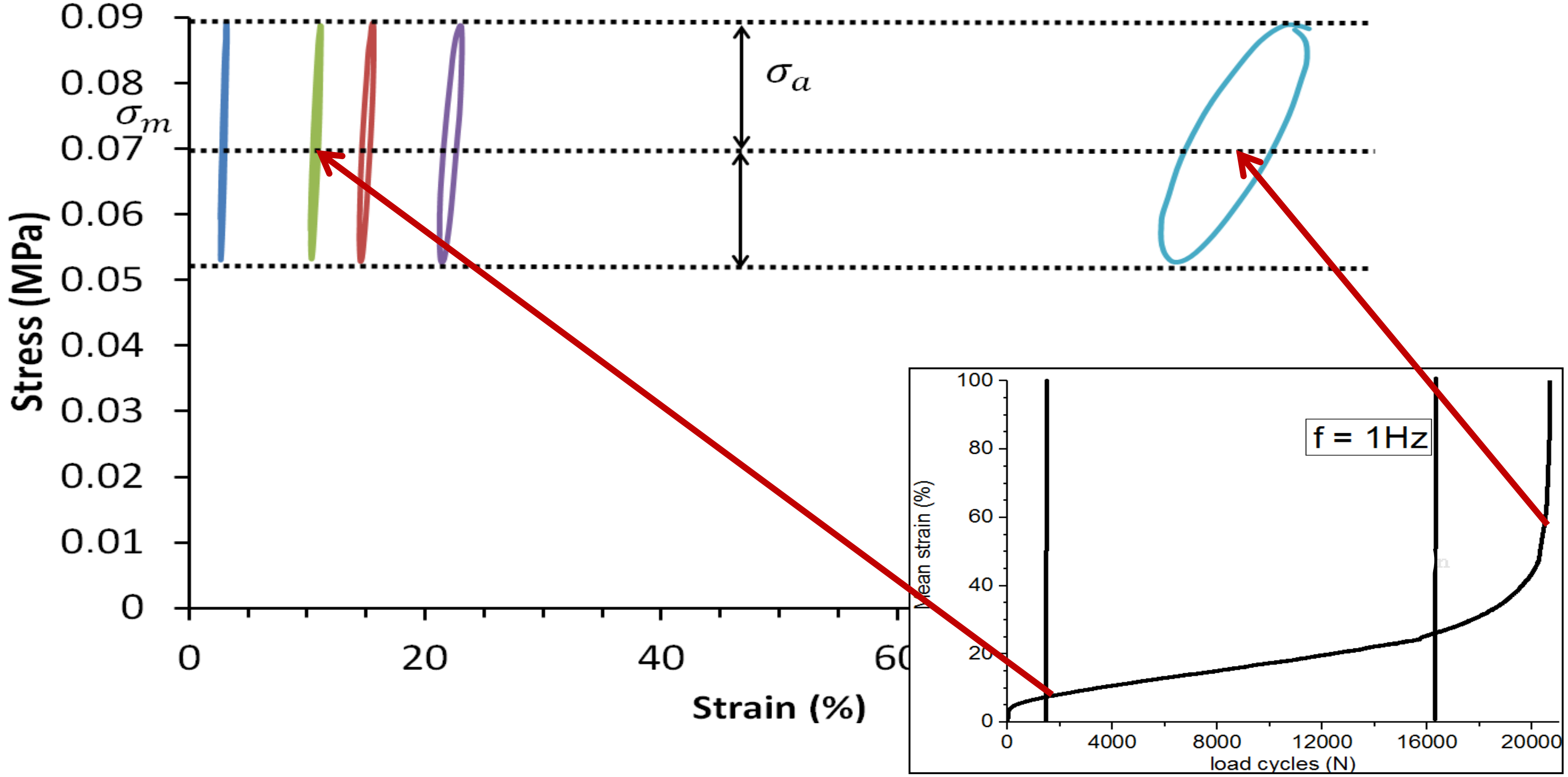
- Preparation of sandwich H-shaped specimen with a transparent acrylic pressure sensitive tape





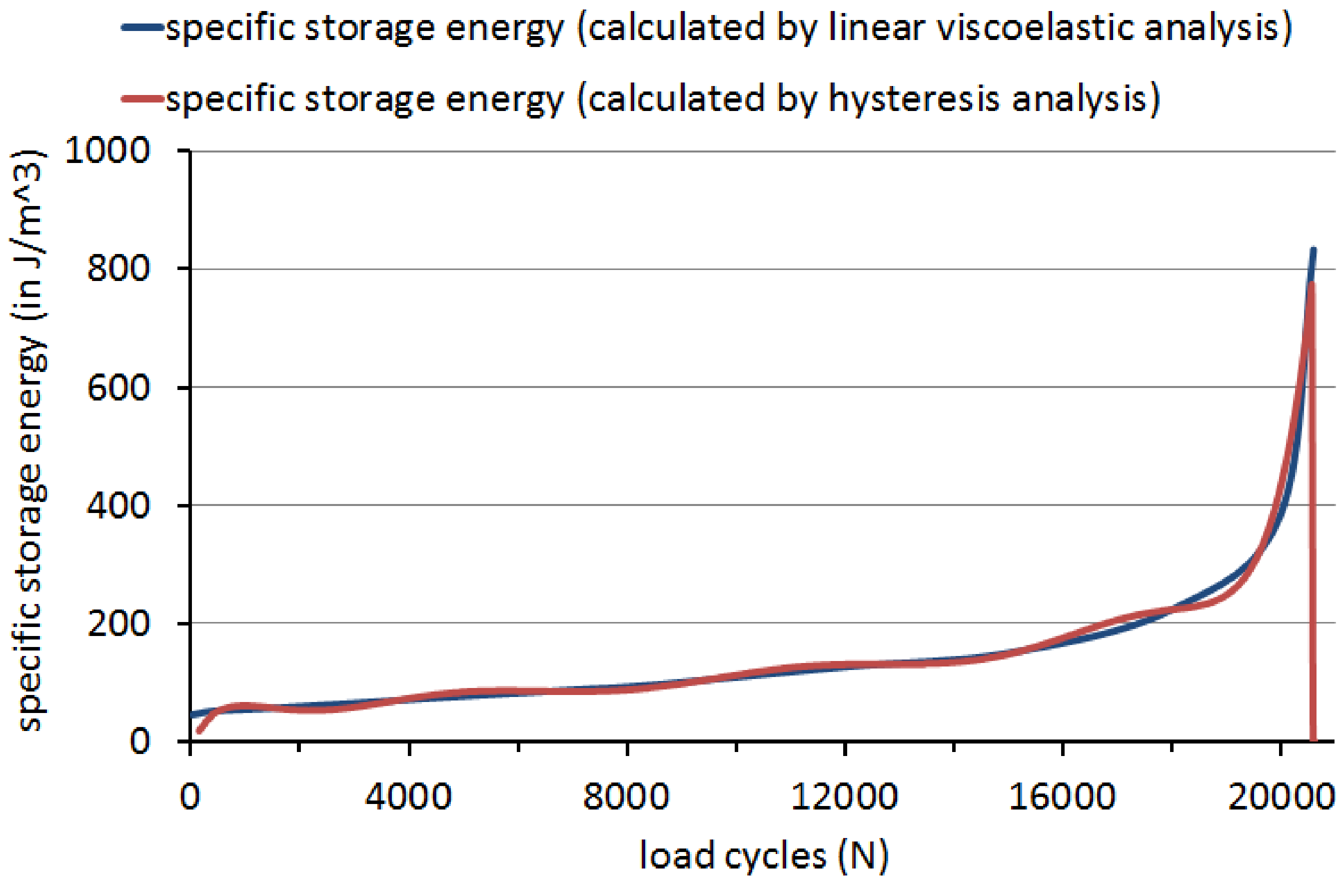
Viscoelastic response to perpendicular stress

- Creep caused by mean static stress
- Change in shape of hysteresis

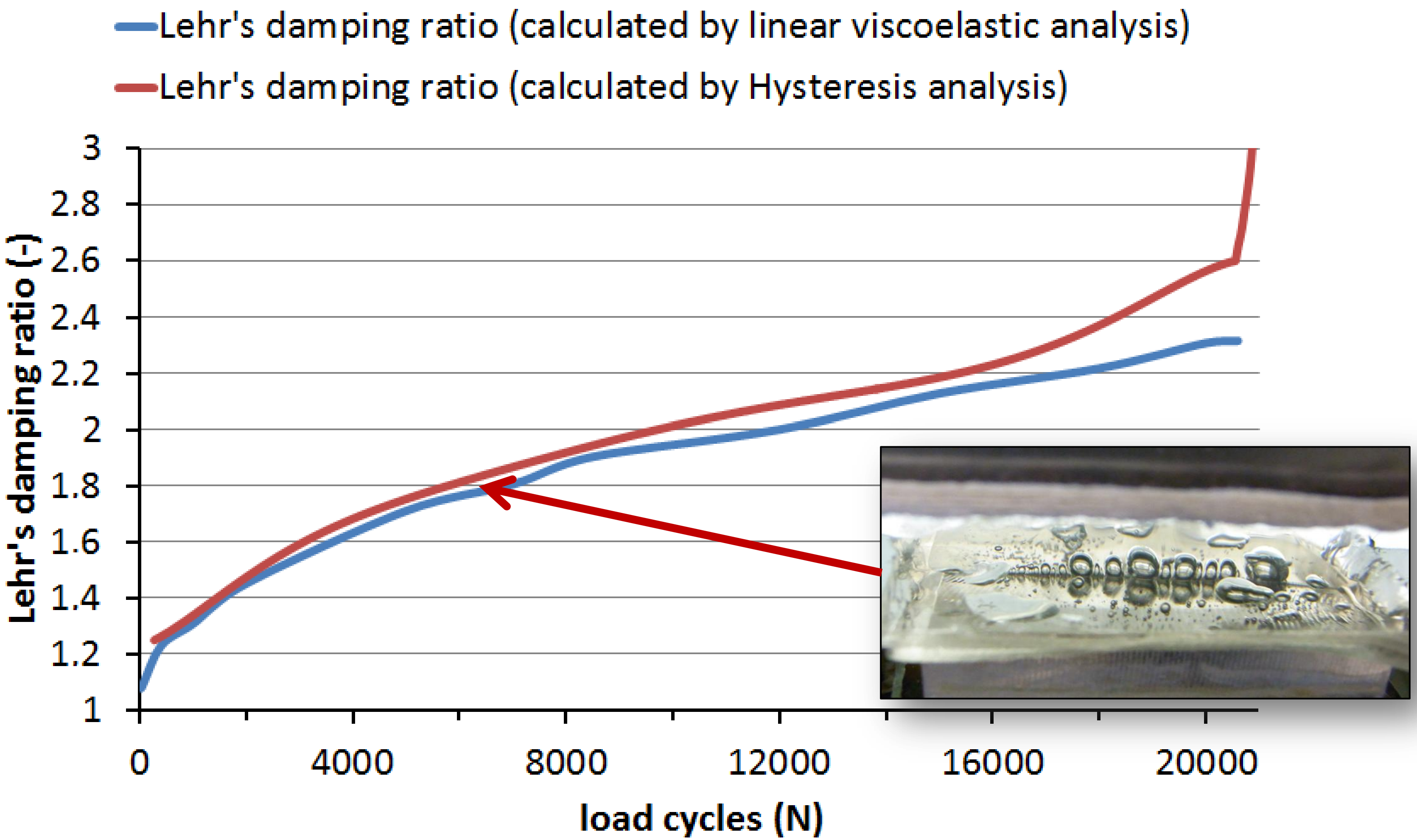


Linear vs. non linear viscoelastic analysis

- No apparent difference in storage energy in the early stage of the experiment



Evolution of defects



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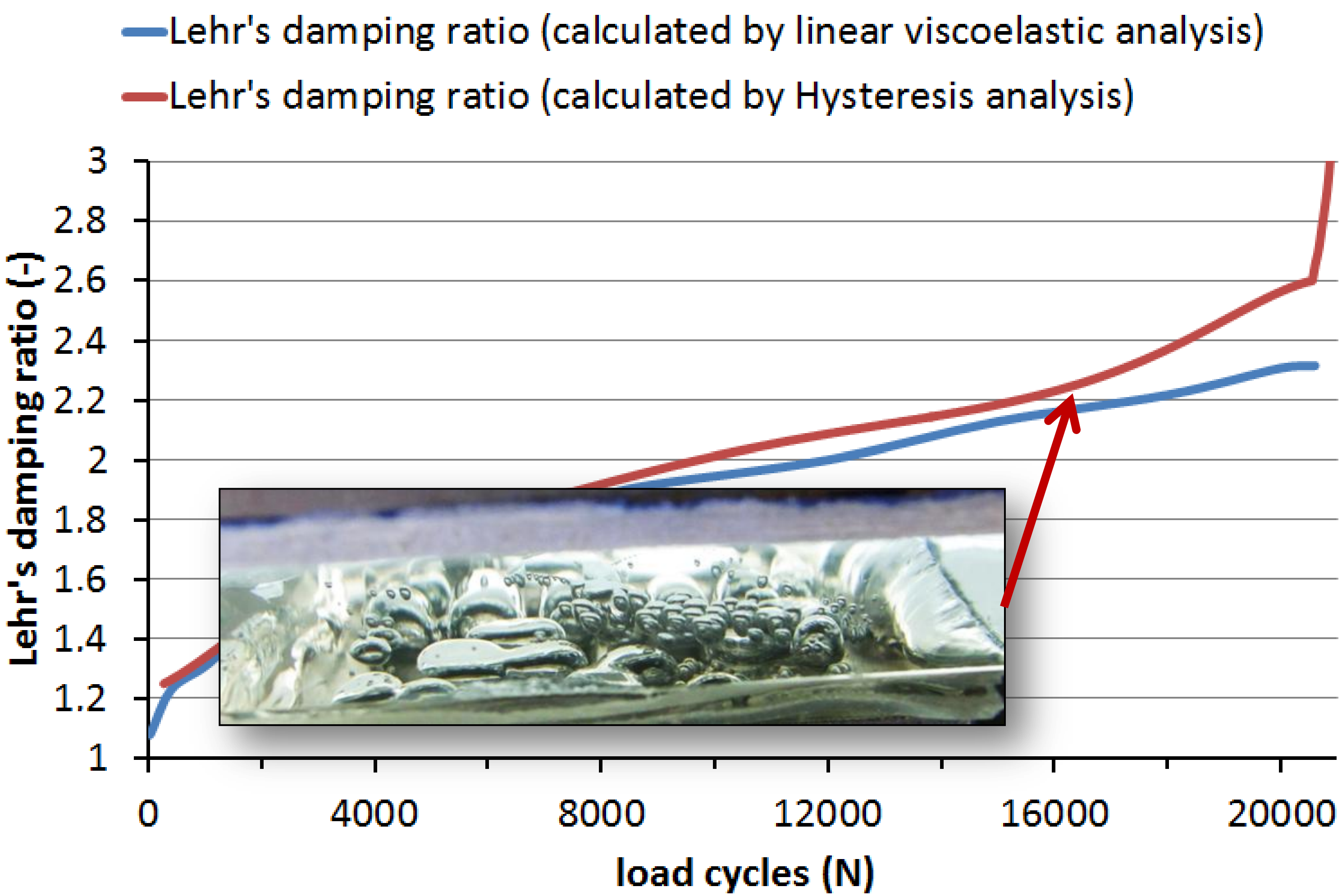

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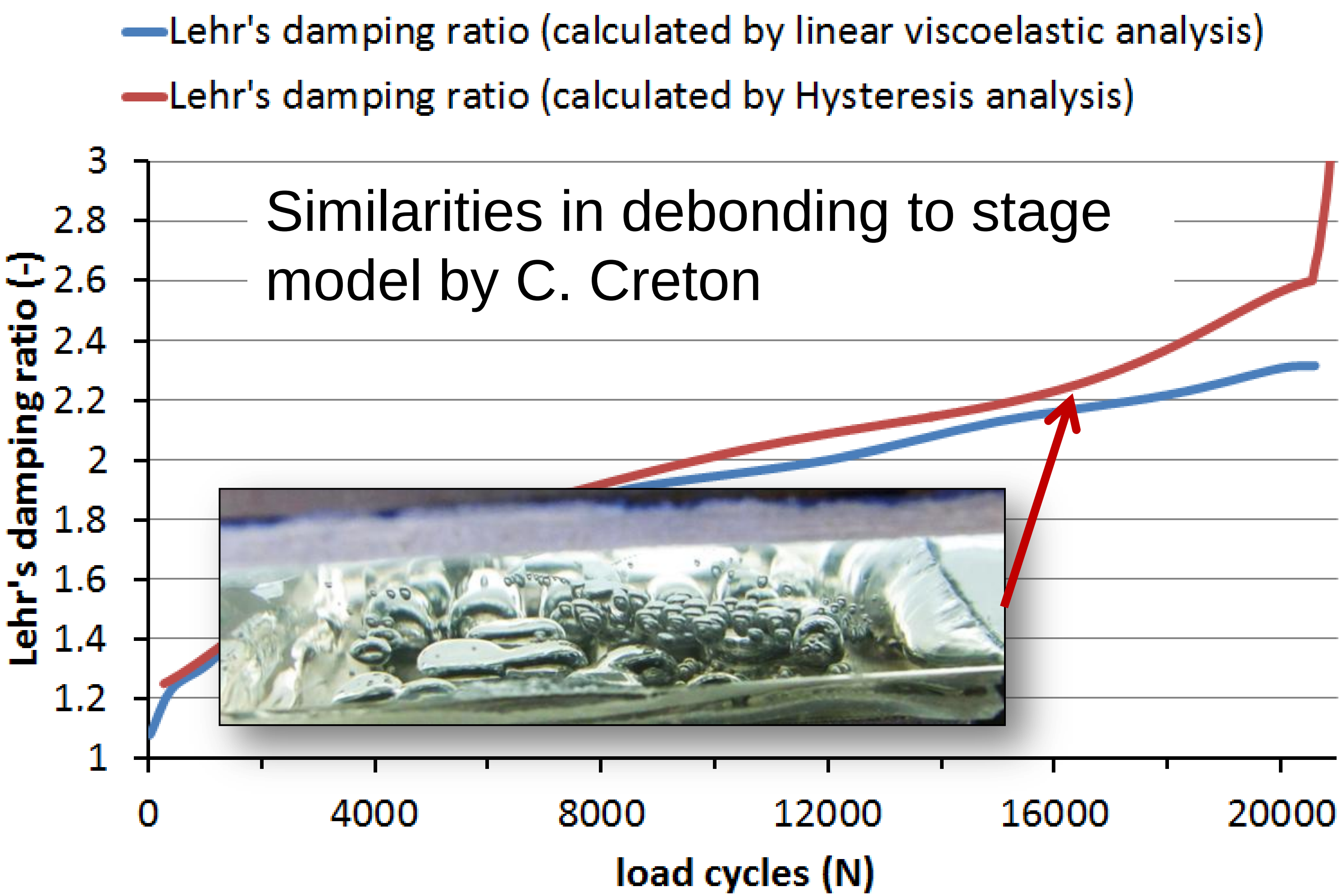

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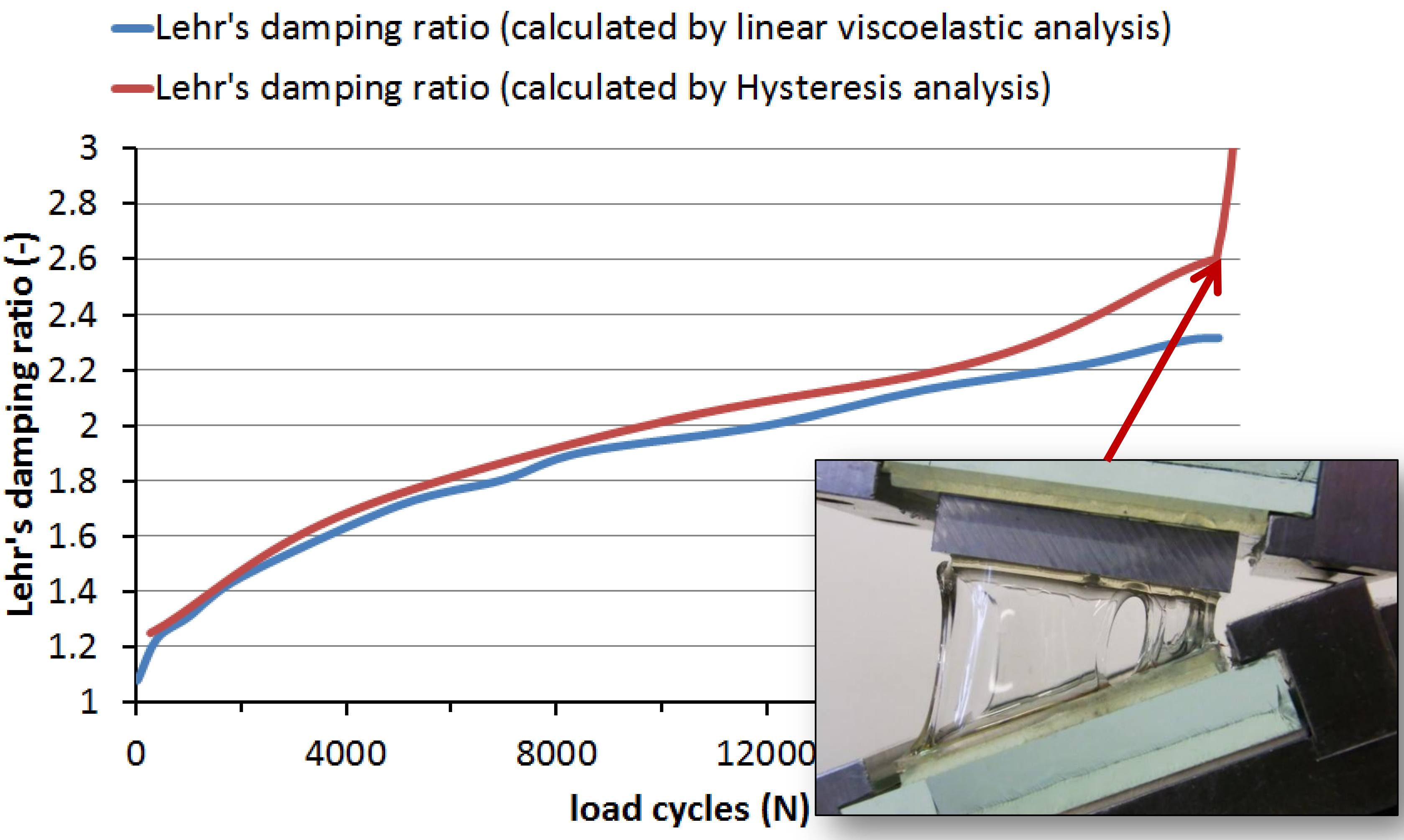
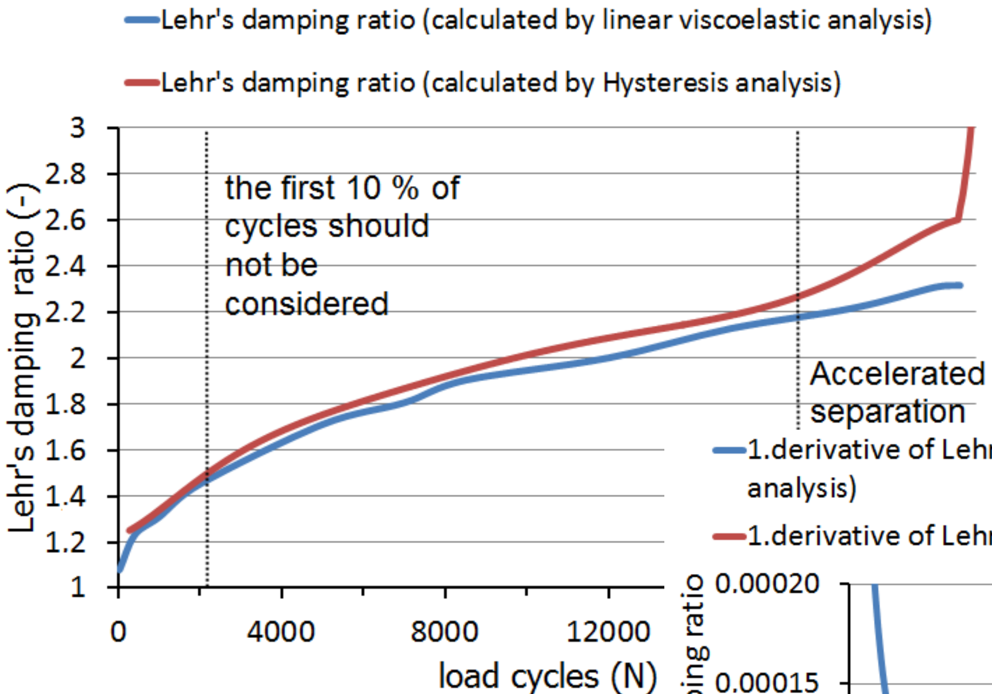
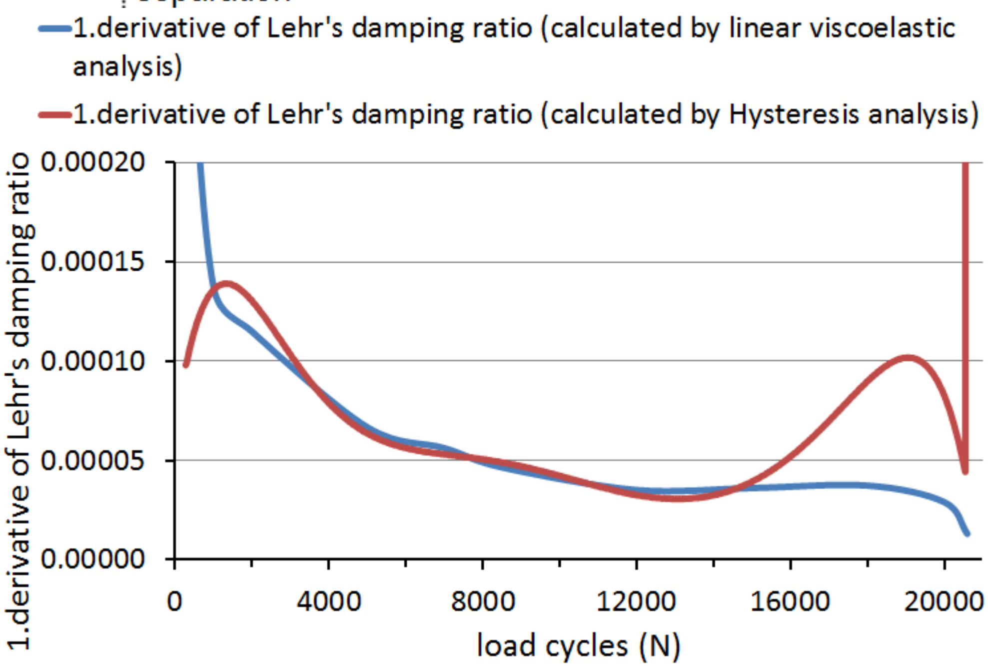


Correlation of failure to Lehr´s damping ratio





Summary

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- Fatigue resistant compliance / loss factor balance is a performance criterion.

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- Dynamic mechanical analysis can be applied to adhesively bonded assemblies.
- Fatigue resistant compliance / loss factor balance is a performance criterion.
- Deviation from linear viscoelasticity may be indicative for failure due to creep and fatigue.

Thank you !