A new method for the mechanical characterization of automotive lithium-ion pouch cells

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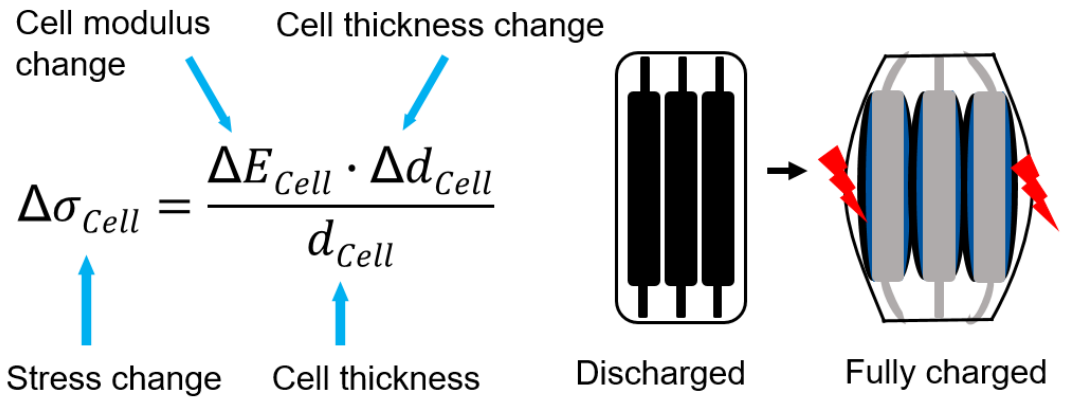
Motivation & Relevance

- Lithium-ion cells change mechanical properties with state-of-charge (SOC) and during aging: cell thickness and also mechanical cell stiffness ([1], [2])
- Mechanical properties of battery cell stacks are highly complex through layered structure of different, porous + electrolyte soaked materials
- Both cell thickness and mechanical stiffness also determine energy density in compressed electrode stacks (e. g. hardcase cells)



References
[1] Deich, T., Hahn, L. S. et al., *J. Energy Storage*, **28**, 101192, 1-12 (2020)
[2] Qi, Y. et al., *J. Electrochem. Soc.*, **161** (11), F3010-F3018 (2014)

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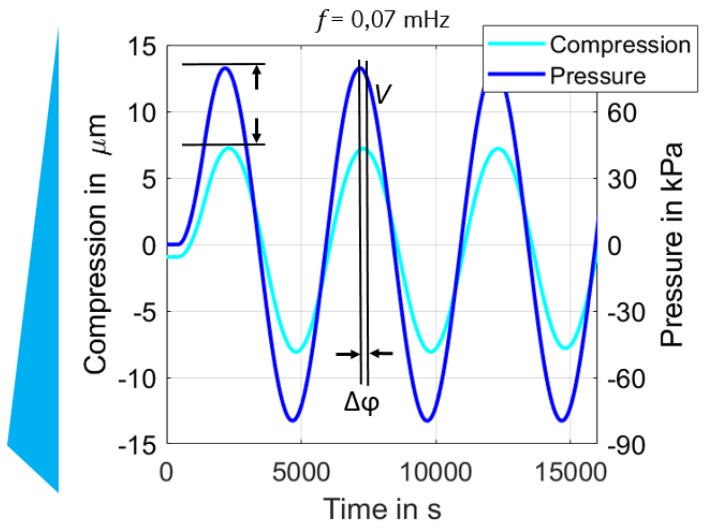
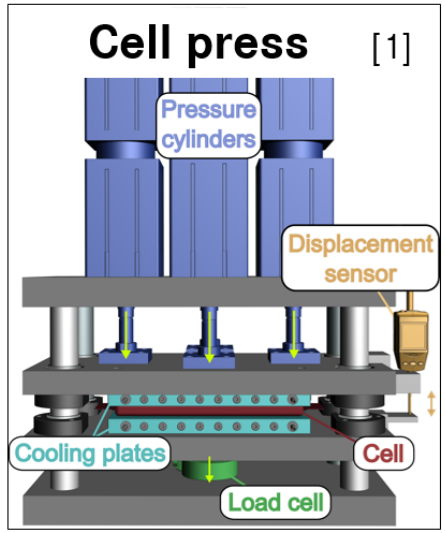
Experimental

- Sinusodial stress σ with freuquencies ω_n applied on cell by in-house developed, fully automatic cell press (details see [1])
- Approx. linear response signal (= compression of cell ϵ) for small defomations in mechanically relaxed steady-state by evaluation of amplification *V* and phase-shift Δφ
- Complex **mechanical modulus** can be derived [3] and fitted to models:

$$\boldsymbol{E}(j\omega_n) = \frac{\sigma(j\omega_n)}{\epsilon(j\omega_n)} = \underbrace{E'(\omega_n)}_{\text{Storage modulus}} + \underbrace{jE''(\omega_n)}_{\text{Loss modulus}}$$





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[1] Deich, T., Hahn, L. S. et al., *J. Energy Storage*, **28**, 101192, 1-12 (2020)

[2] Qi, Y. et al., *J. Electrochem. Soc.*, **161** (11), F3010-F3018 (2014)

[3] Eyerer, P. et al., *Polymer Engineering*, 2. Auflage, Berlin Heidelberg: Springer, p. 552 (2008)

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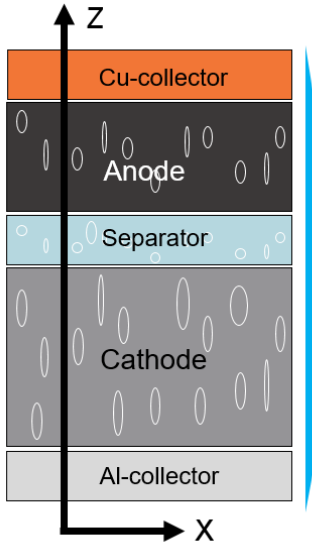
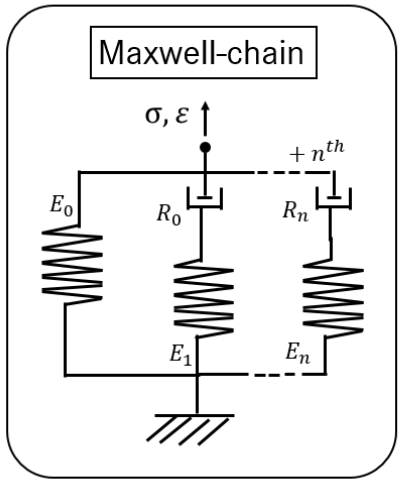
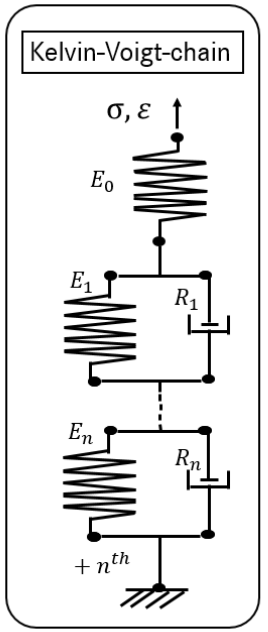
Modeling of compressive mechanical properties

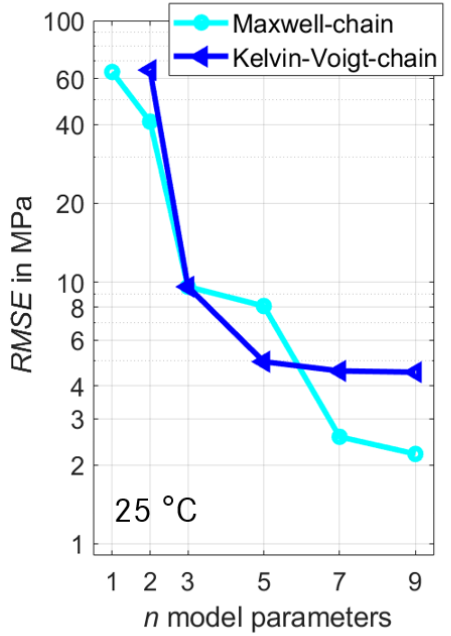
- Mechanical structure reduced to 1D model in cell thickness direction
- Viscoelastic mechanical properties dominant during meaurement (small stress ranges)
- 1D-modeling using rheological models with *n* parameters
  → discretization of complex viscoelastic mechanical behaviour



1D-Modeling in **z-direction** by rheological models







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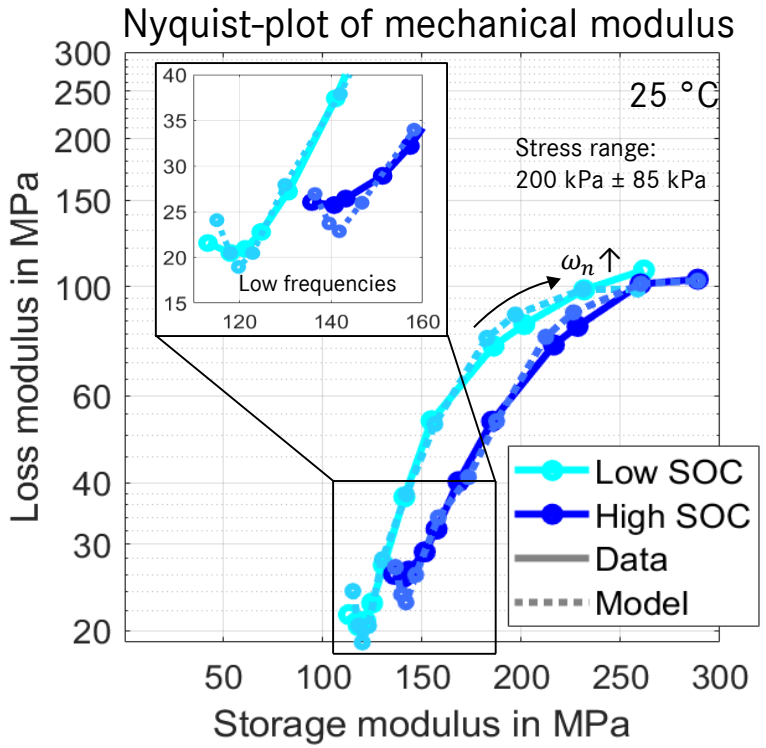
Results

- Elastic properties (storage modulus) dominate compressive mechanical properties
- Fully charged cell ≈ 10 % stiffer than discharged cell
- Relevant E-modulus: $|E_{low\ SOC}| \approx 120$ MPa (low frequencies)
- Viscoelastic behavior of cell stacks is modelled in 1D by spring-damper-models with ≥ 7 elements with RMSEs < 5
- Simple, accurate and extremely flexible modeling of relevant properties of highly complex mechanical battery structure



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Summary

- Mechanical characterization of cell/ stacks is important for optimal housing design
- Mechanical modulus introduced for battery analysis and characterization of large-format cell stacks described by complex ***mechanical cell impedance***
- New domain for cell characterization opened, electrical/ thermal equivalent cicuit modeling to be extended for mechanical modeling
- Mechanical properties‘ change measured and modeled during charge/ discharge measured with non-destructive method and also modeled
- Fully charged cell is stiffer, increased storage modulus (elastic properties)

Outlook

- Further development of methods and models, e.g. including poroelastic & plastic behavior [4]
- Investigation of mechanical properties during different states, e. g. charging/discharging, formation, aging and different cell chemistries
- Insights about mechnical degradation mechanisms, optimal casing design
- Potential method for end-of-line check of wetting/ formation

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[4] Gor, G. Y., et al., *J. Electrochem. Soc.,* **161**, F3065-F3071 (2014)

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