Faserverbundbauteilen unter dynamischen und zyklischen Belastungen

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4a Technologietag 2011
3.-4. März 2011, Schladming

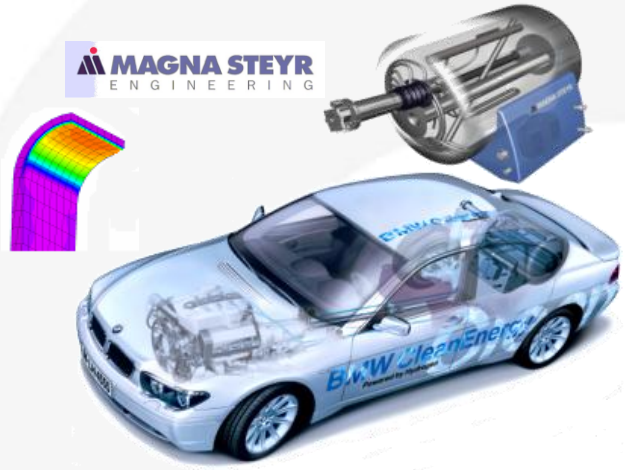
product development

lightweight applications / polymers and composites

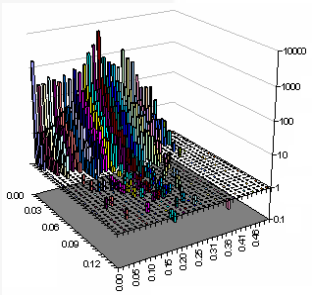
…is this predictable?

product development

lightweight applications / polymers and composites



LH_2 – inner tank suspension
lowest possible heat transfer / BMW clean energy
high stiffness, high strength composite solution
increased performance : 250%

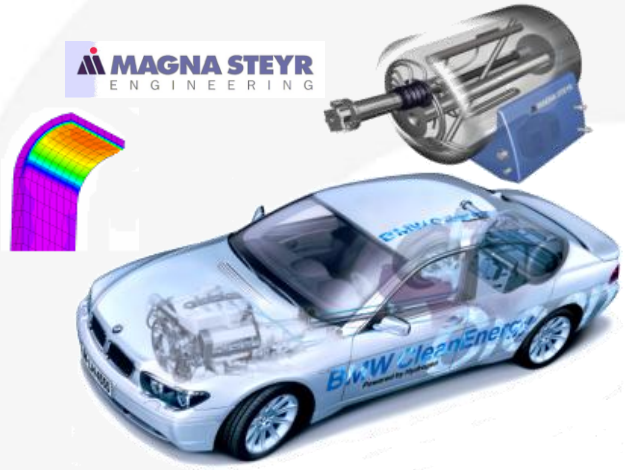


4a fatigue - composites
linear cumulative damage analysis
failure prediction by Puck´s criteria
consideration of anisotropic lay-up

Resin transfer molded carbon brace
substitution of steel brace by RTM carbon brace
with a carbon fiber reinforced plastic – solution
60 % weight reduction

product development

lightweight applications / polymers and composites



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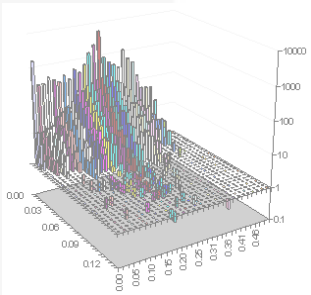

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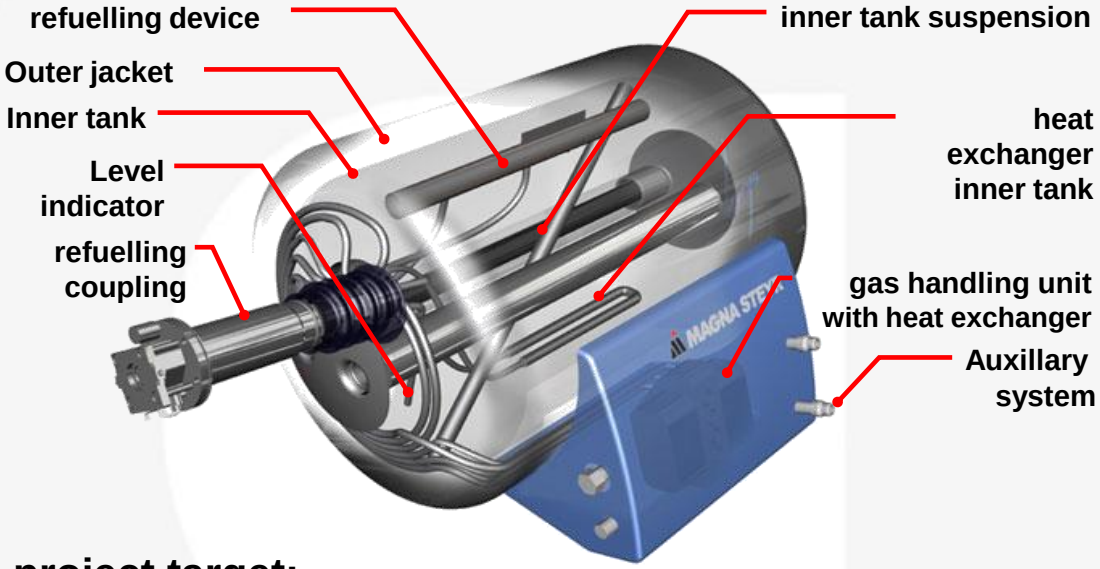
example: development LH2 - tank suspension



reasons for using composites:

- stiffness
- strength
- weight
- heat conduction

project target:

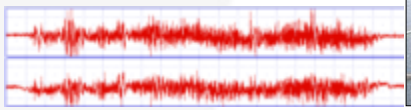
- as low as possible warmth penetrate into the inner tank
- max. place exploitation – filling volume
- observance of the load requirement during the drive and the crash

project: **Kryogener LH2 - Tank**

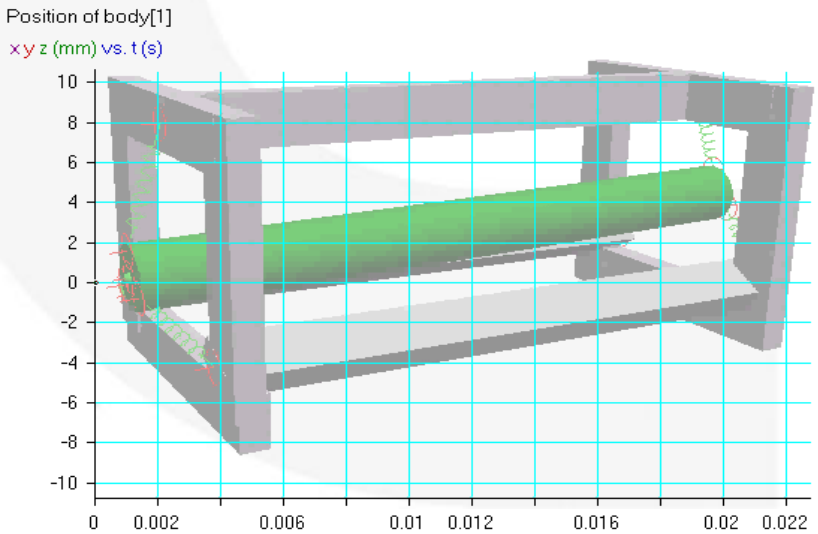
partner: MAGNA STEYR ENGINEERING

LH2 - tank suspension defining test setups

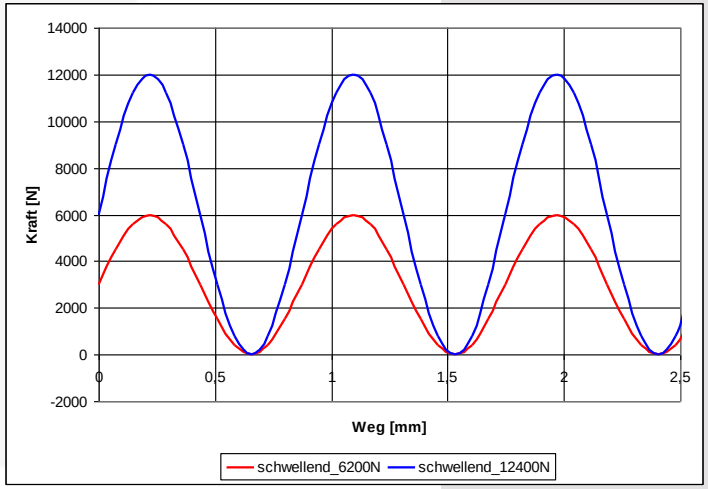
tests on bad gravel roads



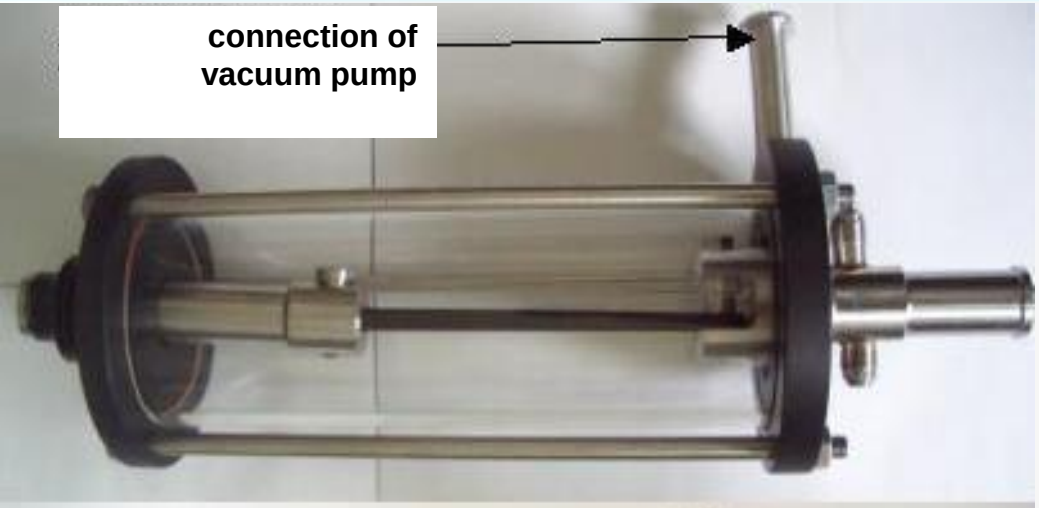
multi body simulations

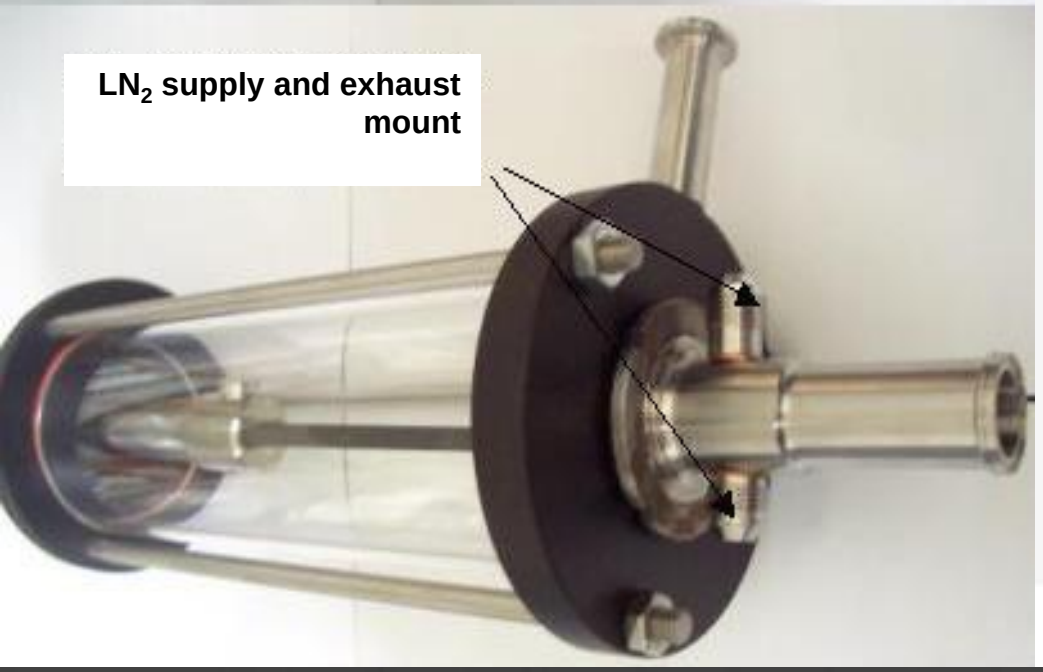


load kN	speciments	frequence Hz	bolt angle	load cycles ca.
test1: part load/cycle curve at 77K				
6.5	3	10	3	1000
9.1	3	10	3	10000
10.1	3	10	3	50000
12.1	3	10	3	1000000
test2: reference with paralell bolts at 77K				
14.5	3	10	0	50000
test3: reference at room temperature				
14.5	3	10	0	50000
14.5	3	10	3	50000



LH2 - tank suspension equipment and test setup





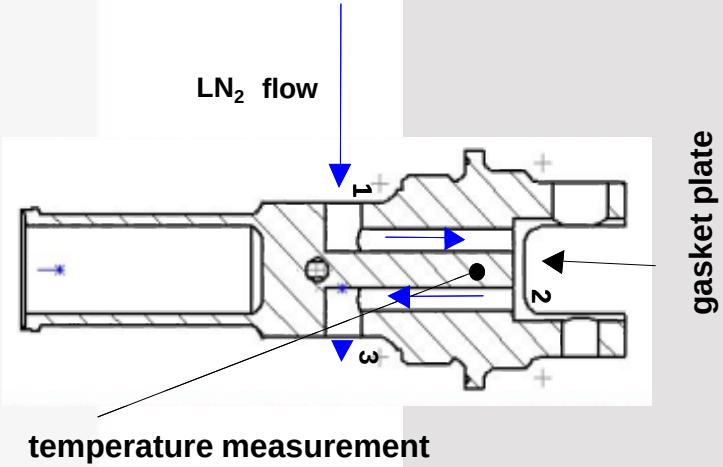
realistic test setup

One side is cooled to 77K

High vacuum inside

Angular position of Bolts

Additional isolation during test – radiation shields

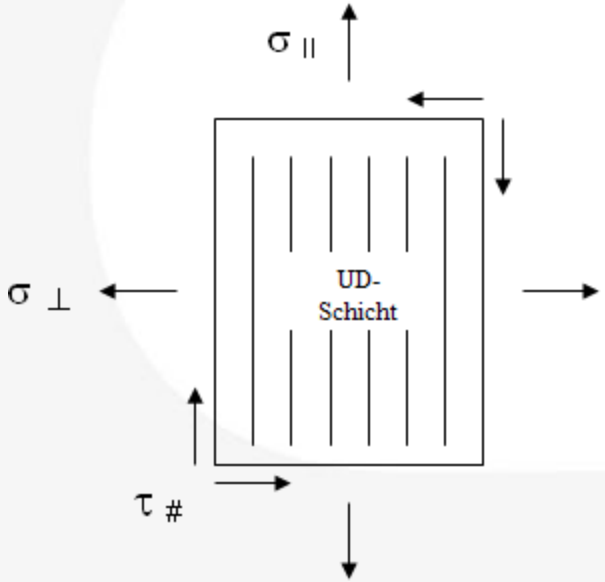


LH2 - tank suspension equipment and test setup

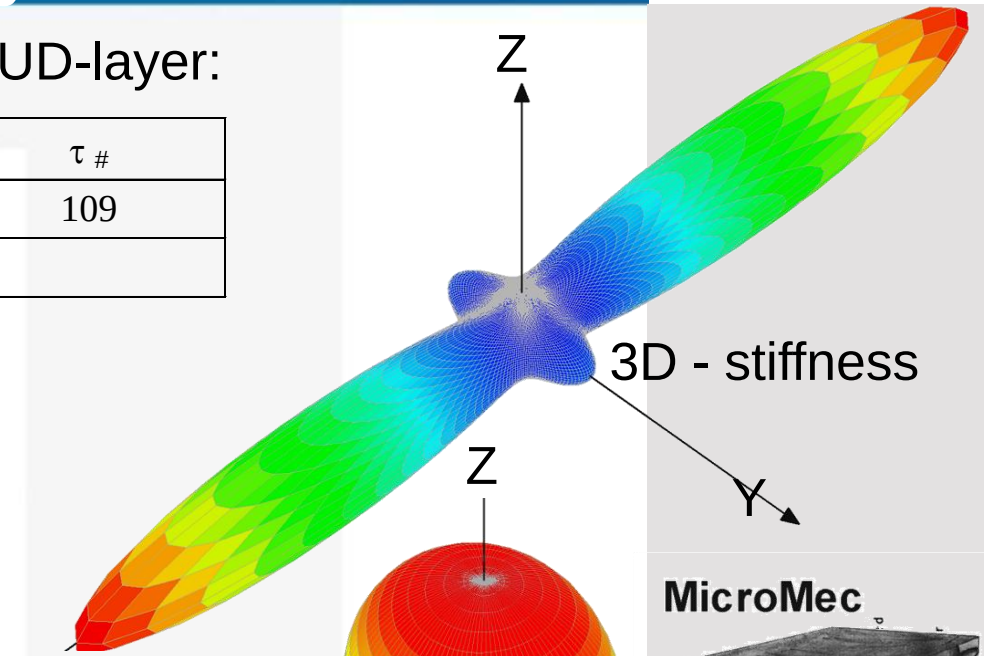
LH2 - tank suspension
CFRP – unidirectional Layer

Typical strenght values of a CRFP - UD-layer:

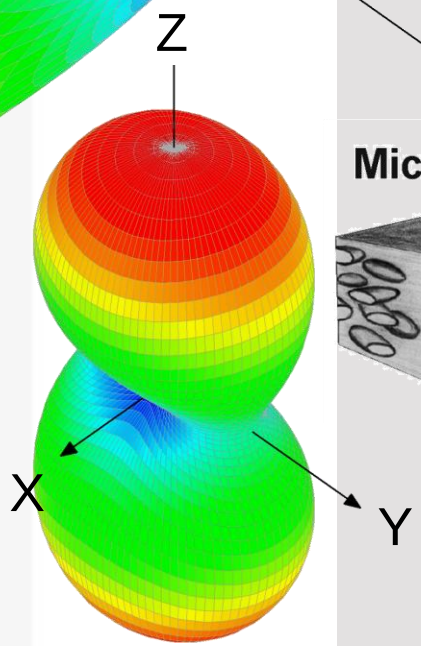
IM7/977	$\sigma_{\parallel}$	$\sigma_{\perp}$	$\tau_{\#}$
Zug	1430	**36**	109
Druck	-900	-218	



- 2-D ply stress
- local coordinating system
- τ^{ils} interlaminar shearstrenght



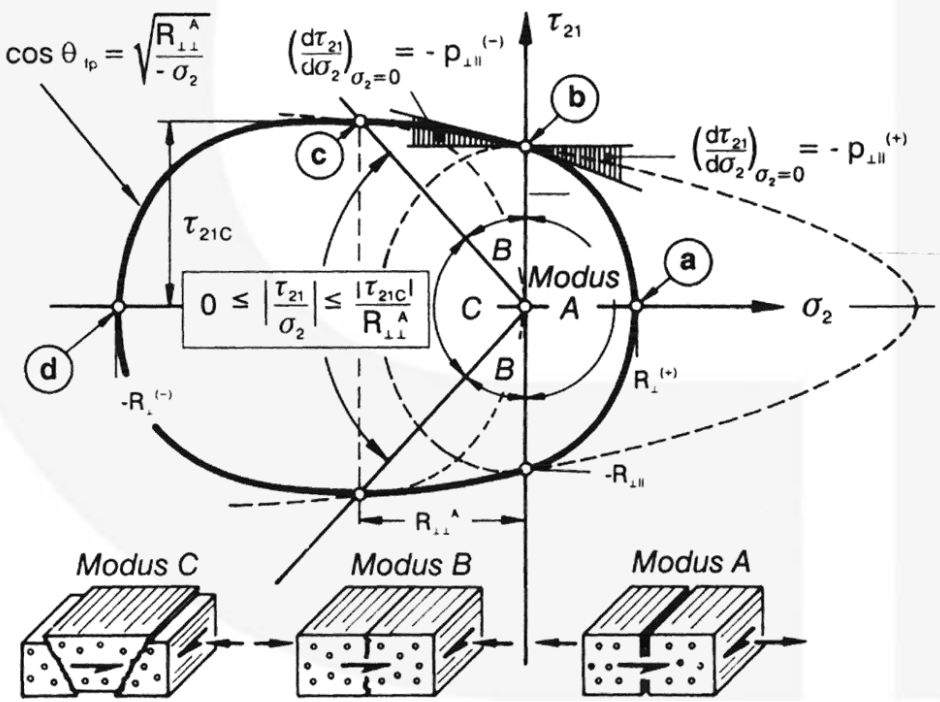
3D - stiffness

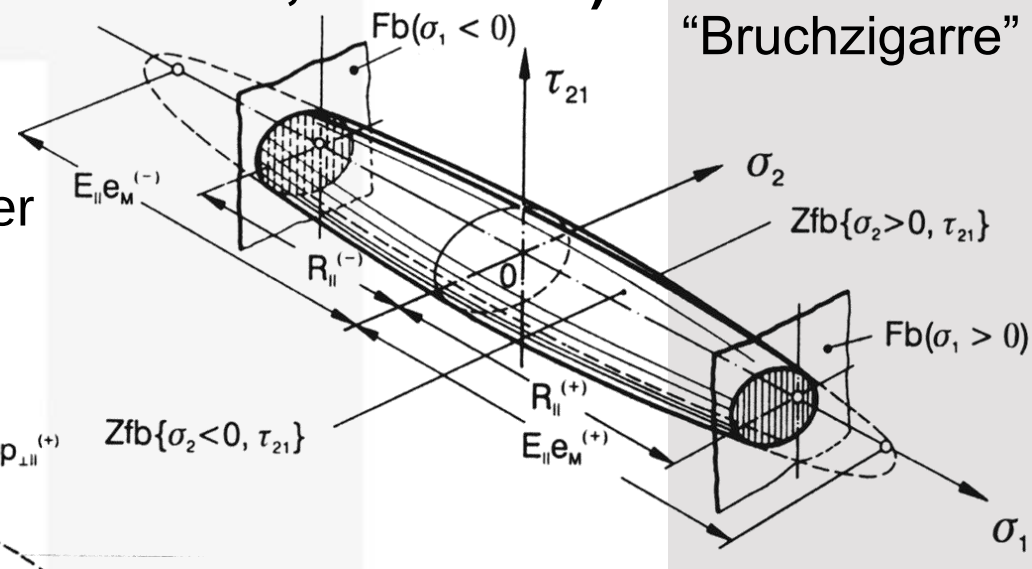


3D – thermal expansion

combined failure criteria (puck's law, hashin…)

- fiber- and matrix-failure mode
- standby factor for matrix und fiber





"Bruchzigarre"

- matrix-failure mode :
  - tension
  - shear
  - "Sprengbruch"

- also for 3D stress states are covered

LH2 - tank suspension
modeling the fatigue-strength

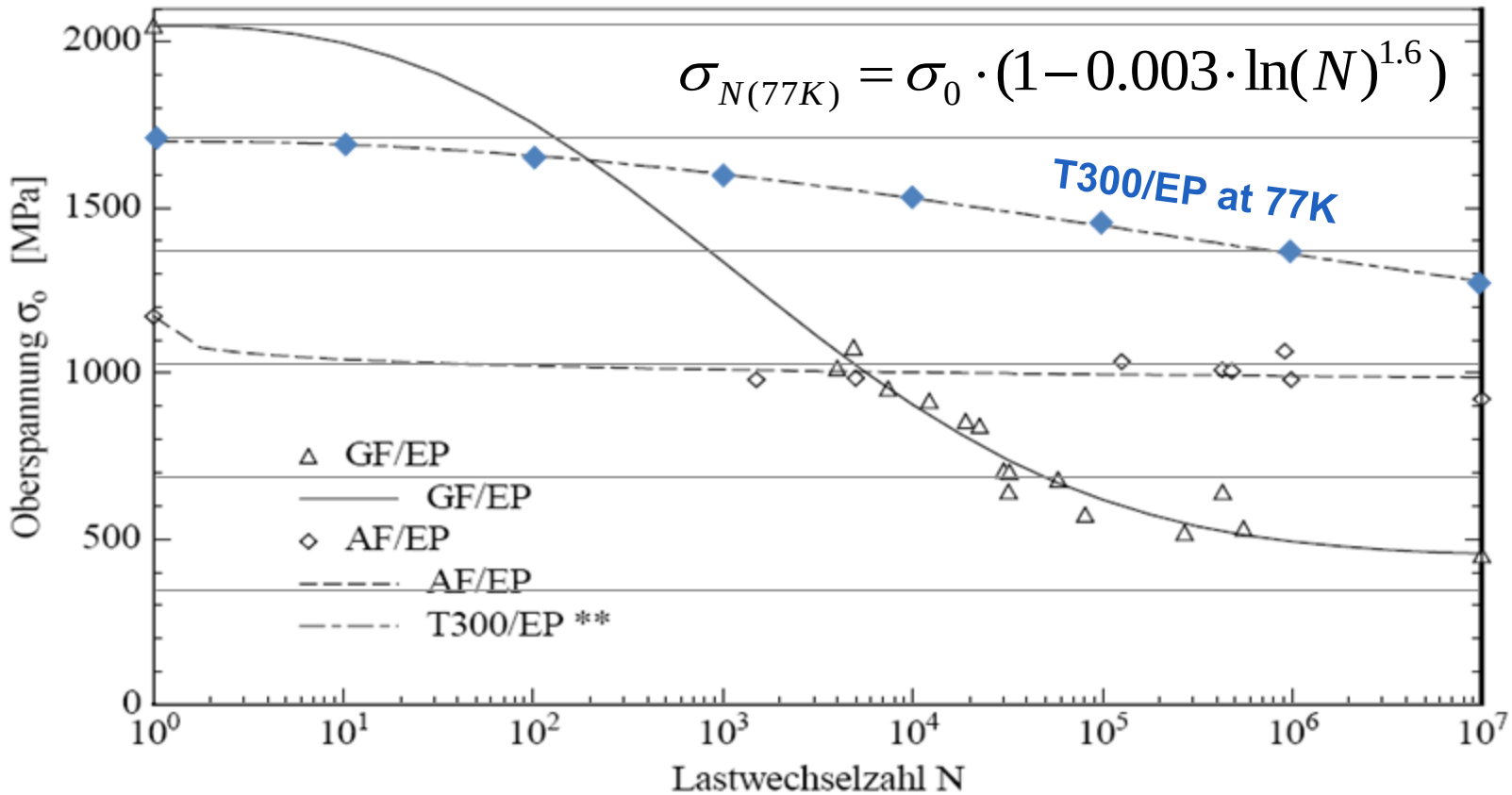
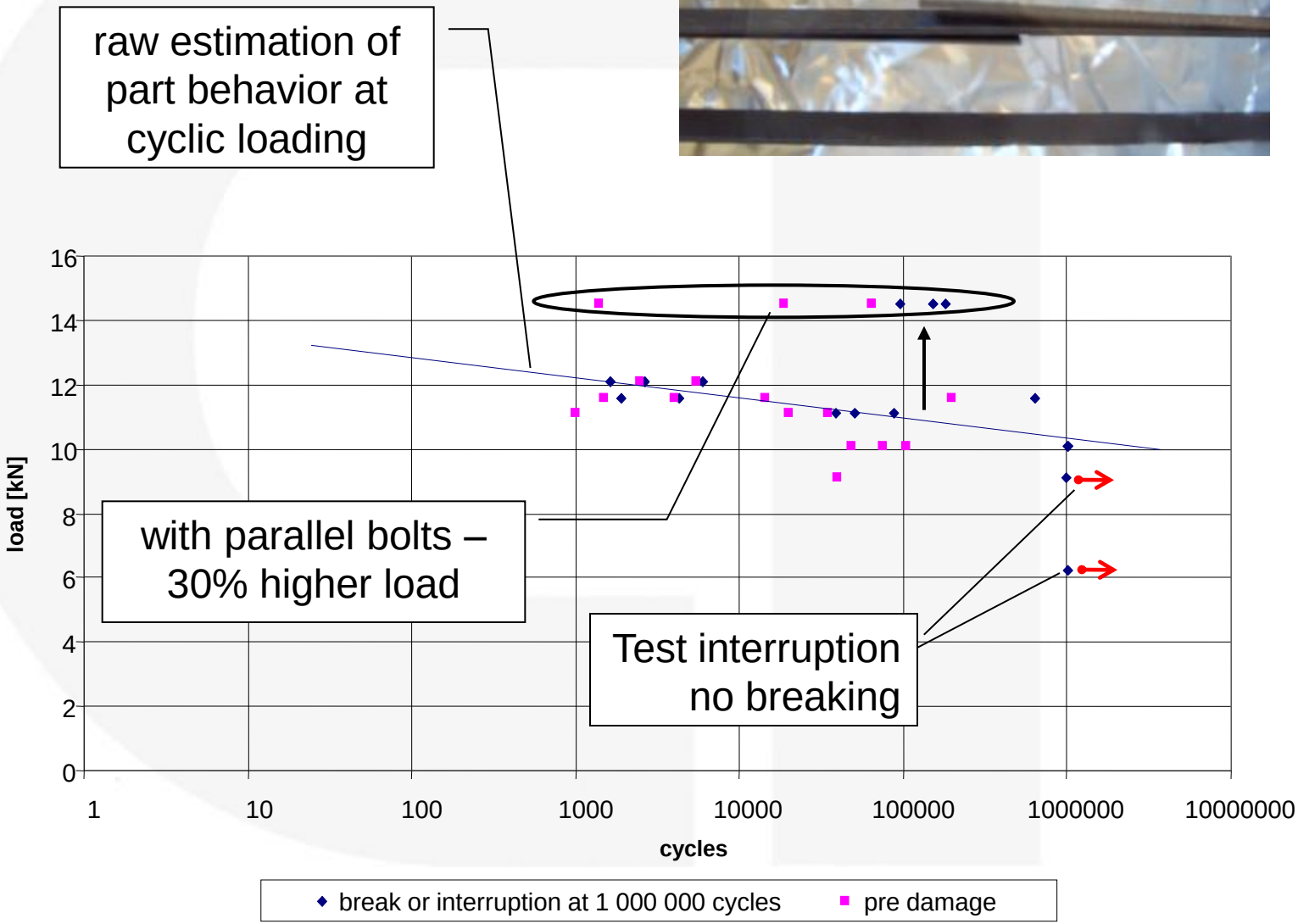


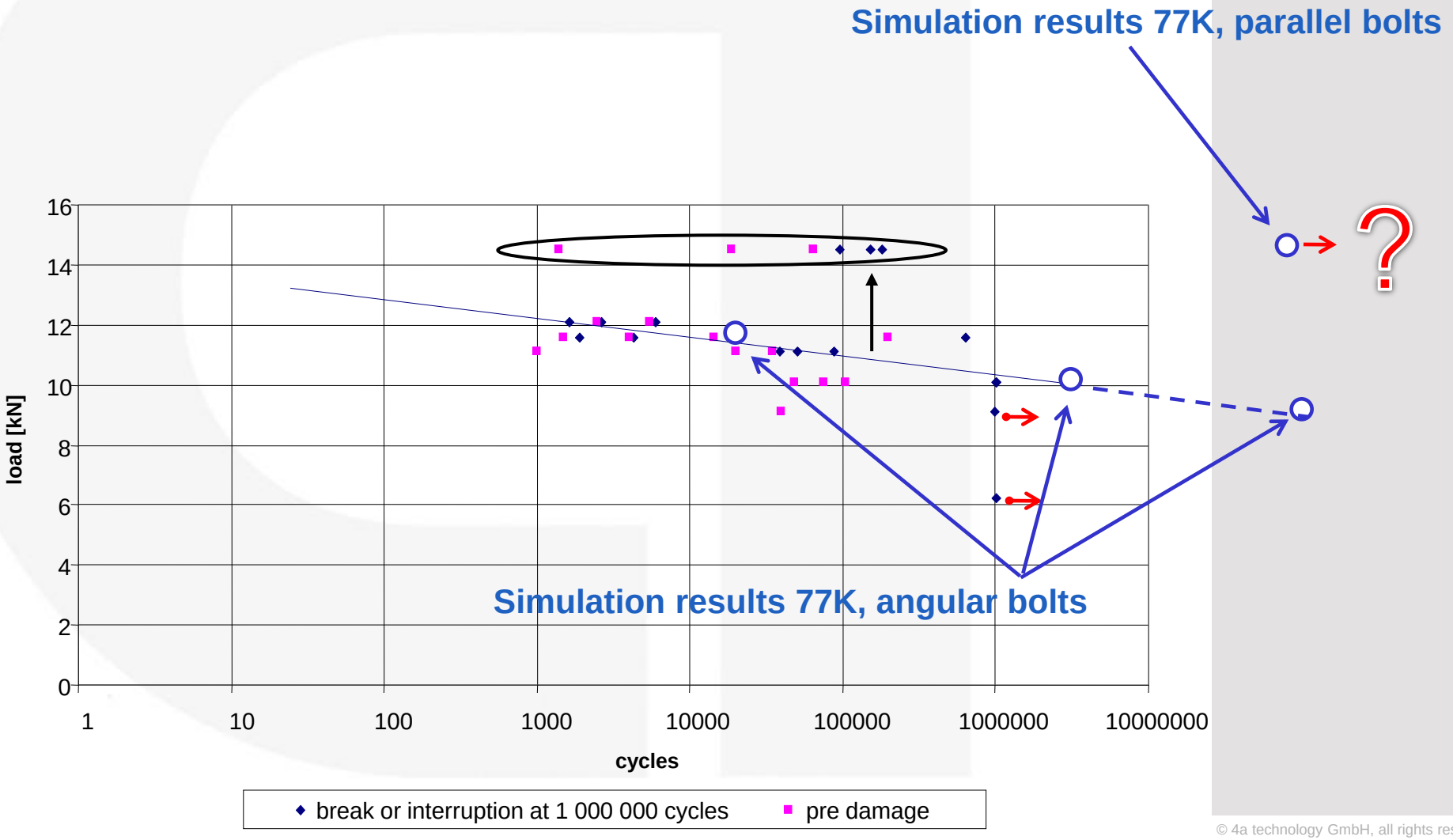
Abbildung 5.8: σ_o–N Diagramm verschiedener UD Verbunde unter schwellender Zugbelastung bei 77 K; R=0,1

**) aus [Pannkoke 92], S. 68

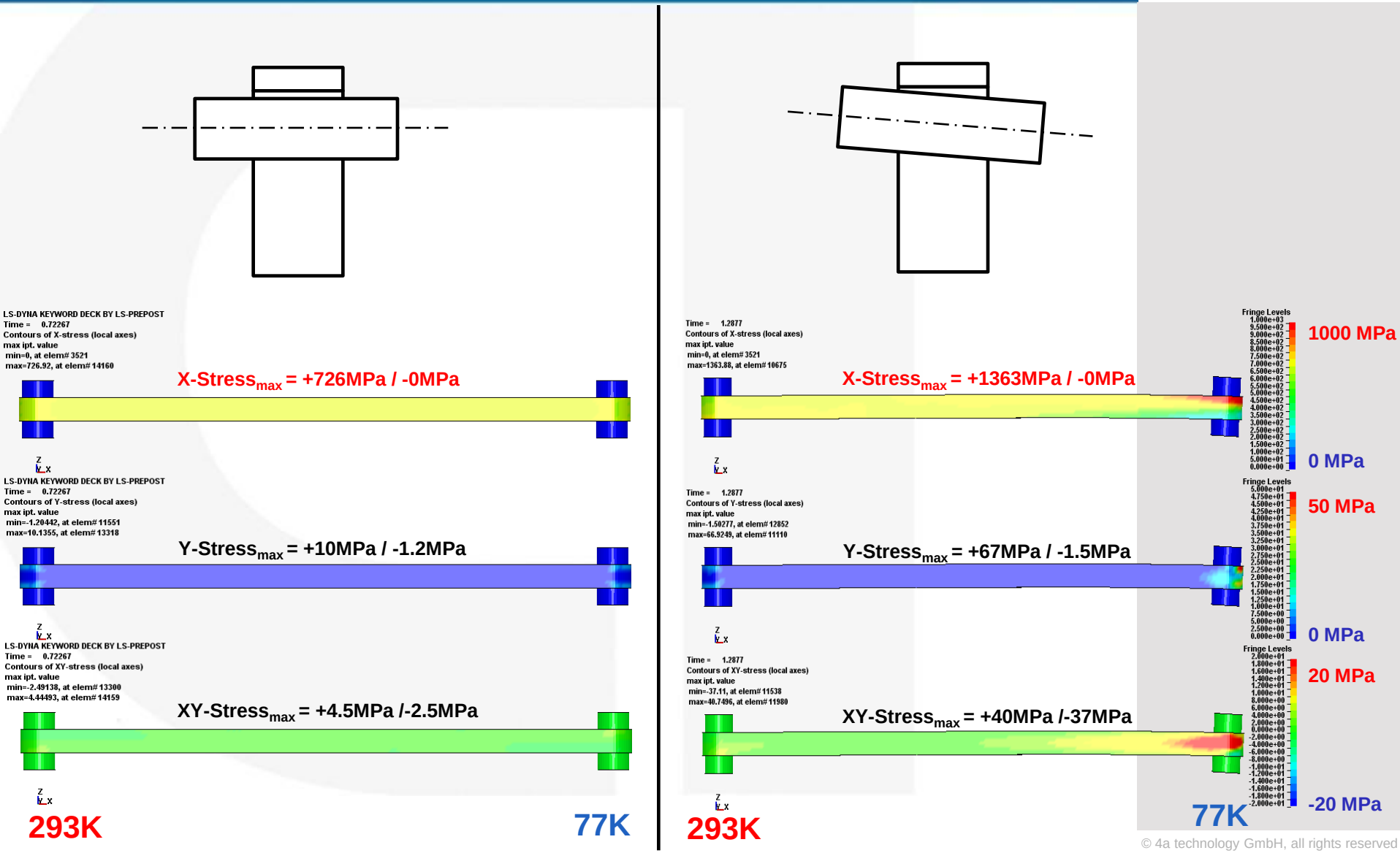
LH2 - tank suspension cyclic loading at 77K



LH2 - tank suspension
prediction of load cycles

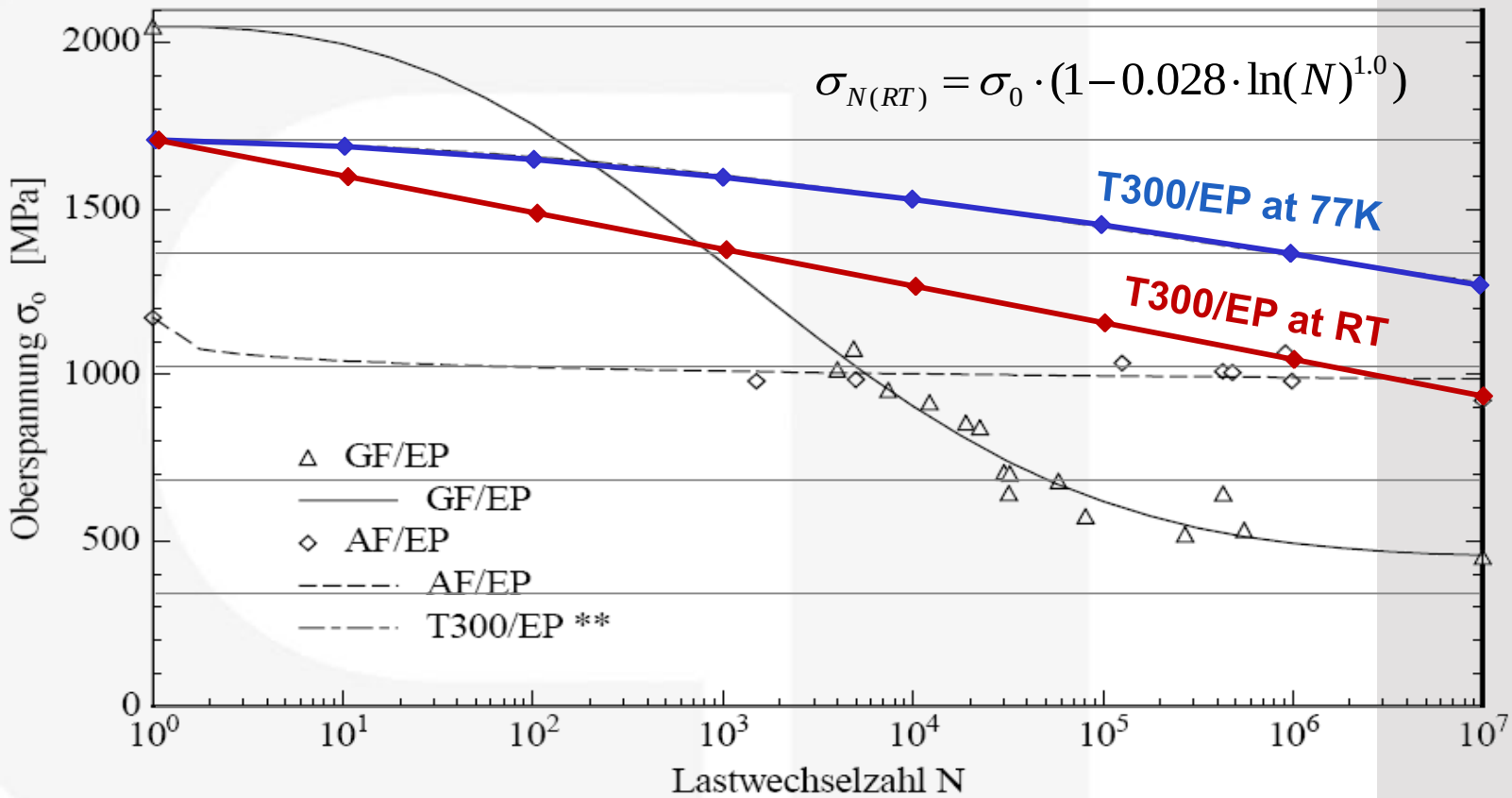


LH2 - tank suspension simulation - parallel bolt position (at 10kN)



LH2 - tank suspension

S-N-curves, effect of temperature



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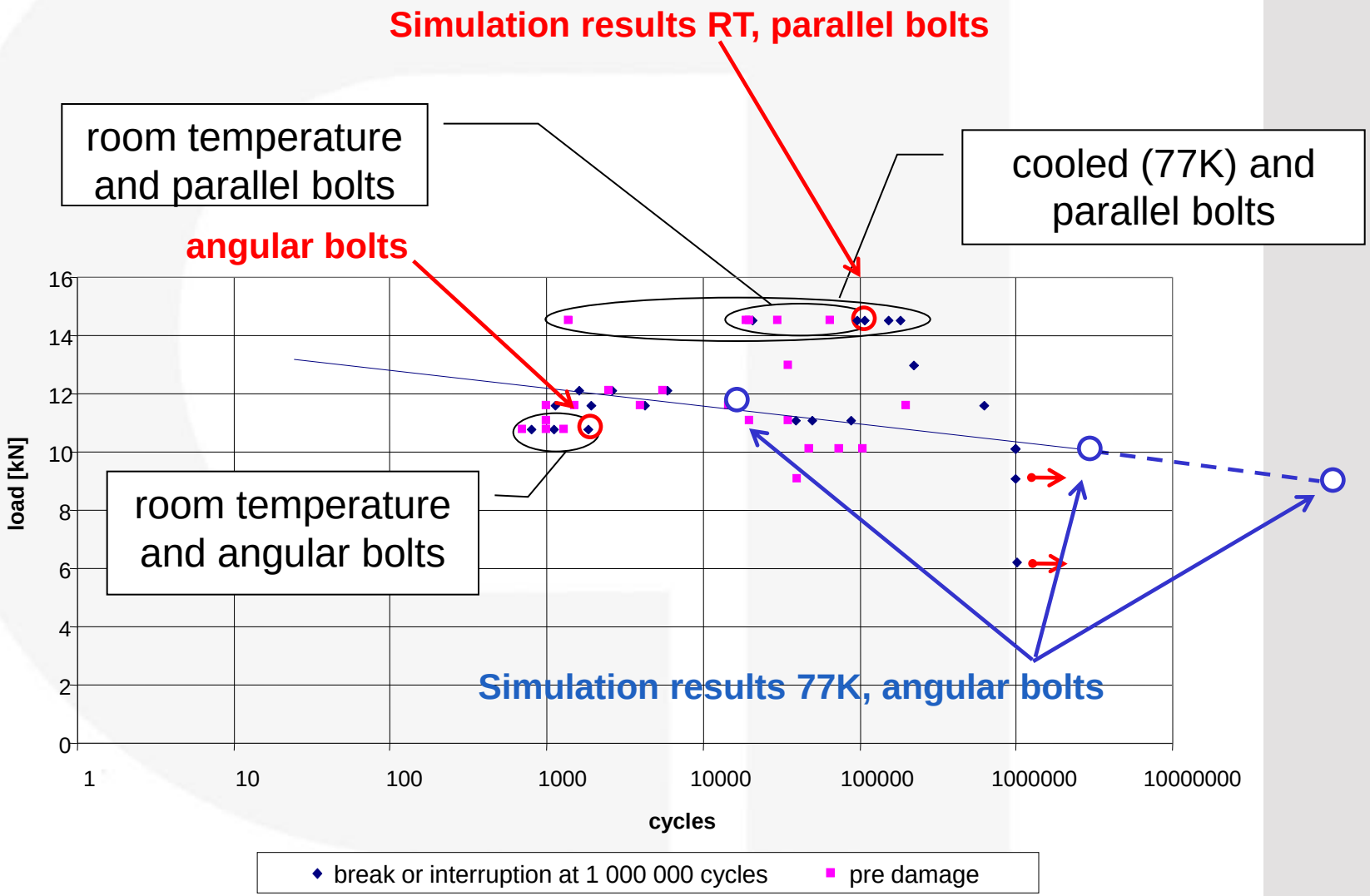
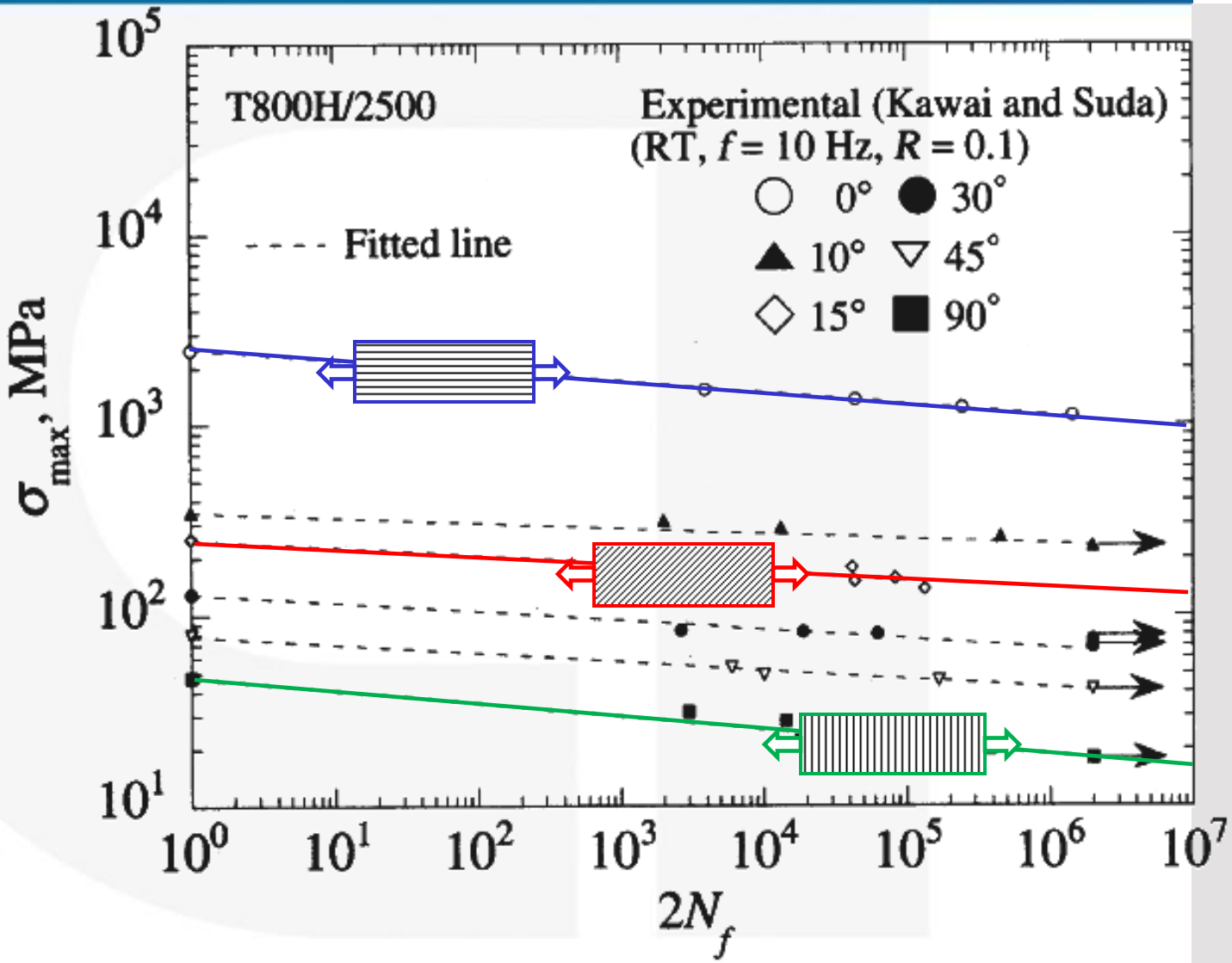
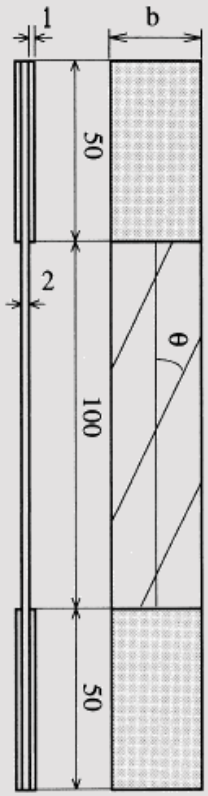
LH2 - tank suspension
comparison with simulation results



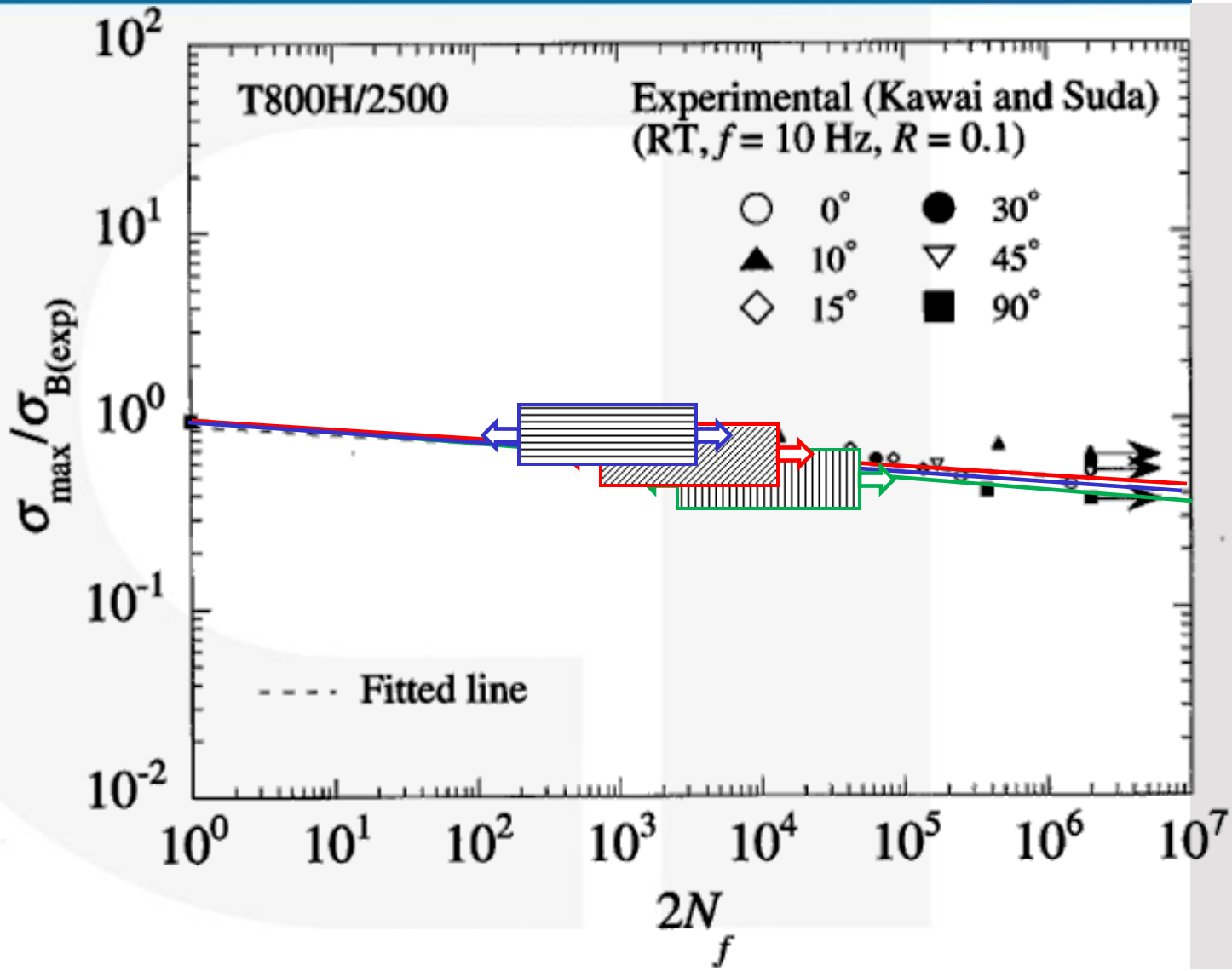
LH2 - tank suspension
effect of fiber orientation (UD)

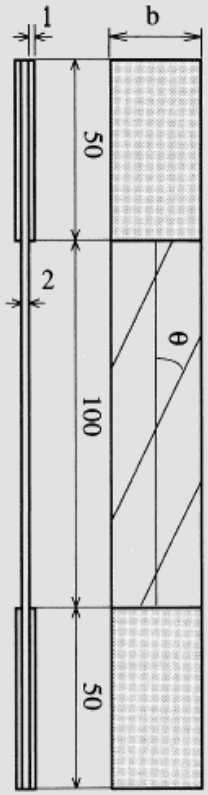




LH2 - tank suspension

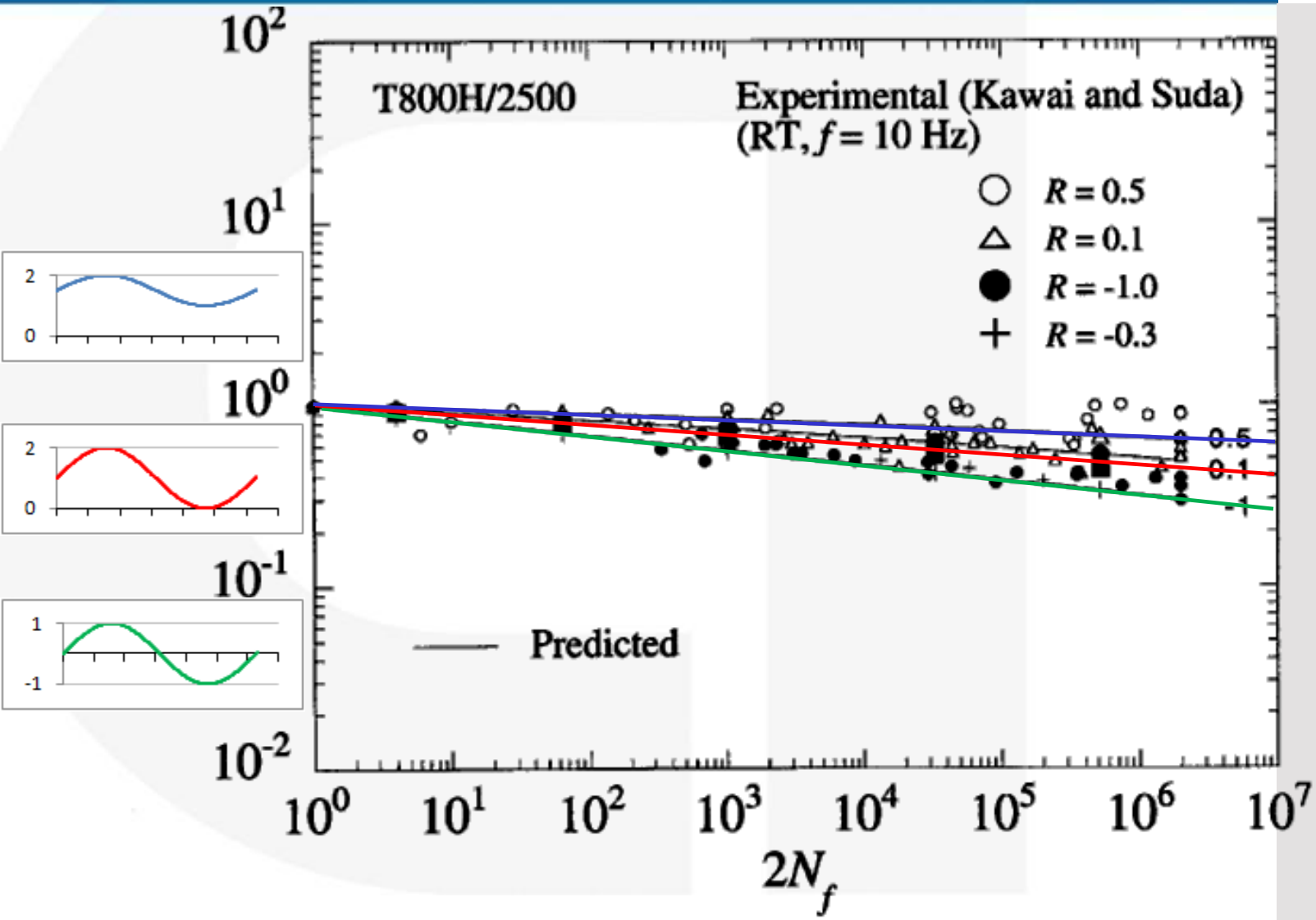
effect of fiber orientation (UD) - normalized

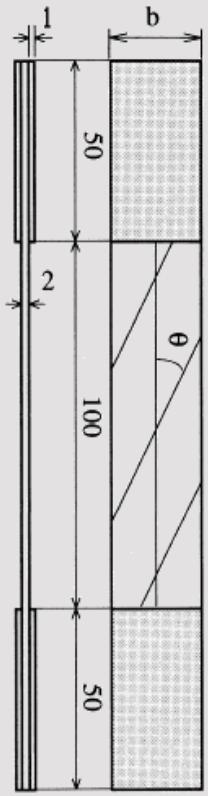




LH2 - tank suspension

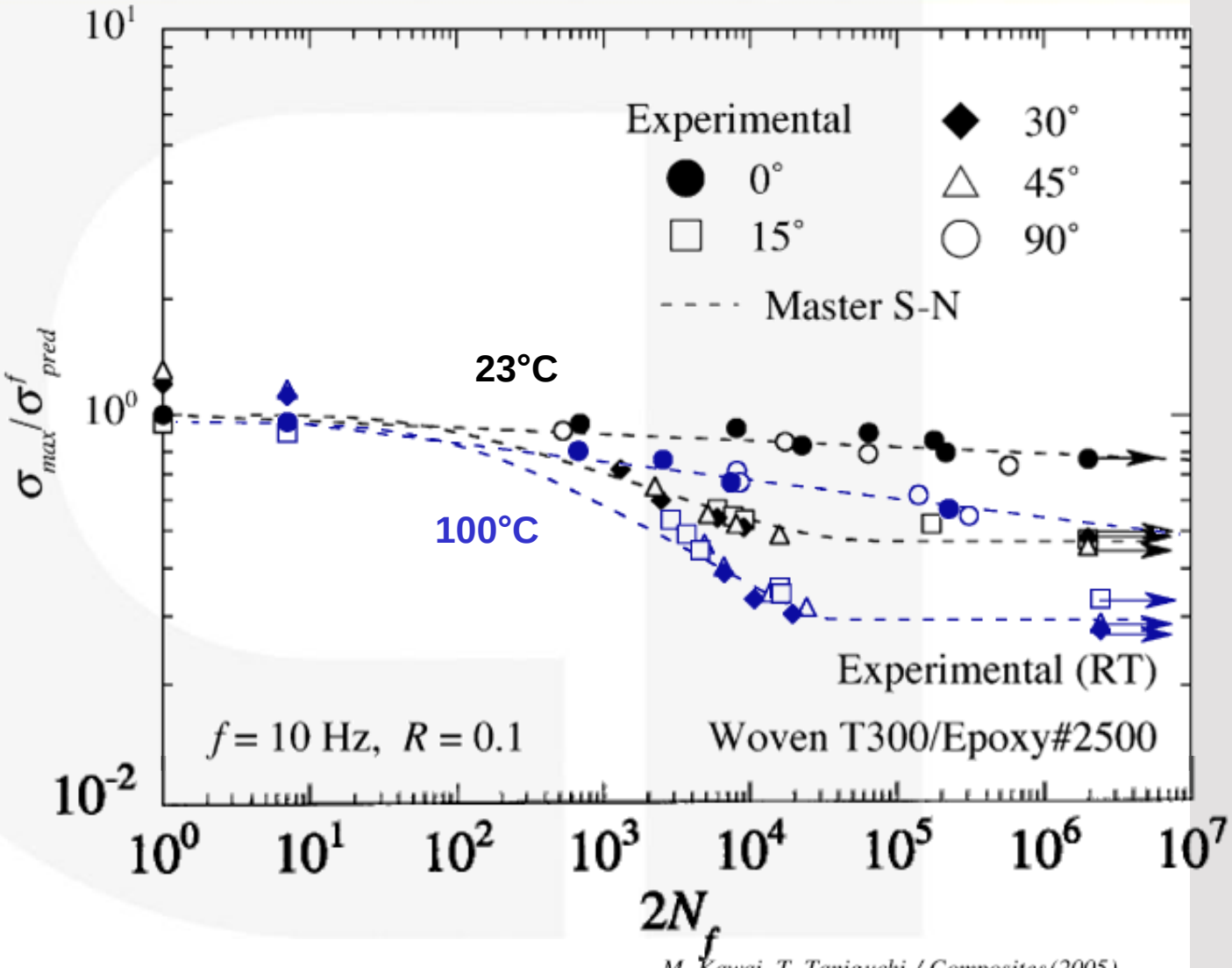
effect of stress ratio (e.g. CFRP)

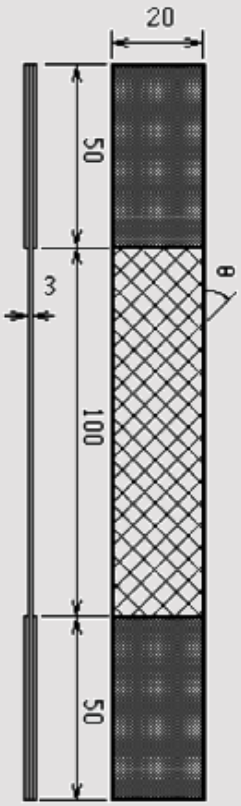




LH2 - tank suspension

effect of off- axis load on fatigue behaviour

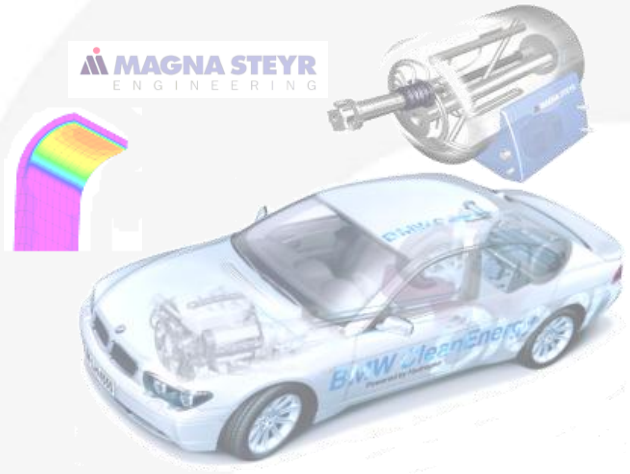




M. Kawai, T. Taniguchi / Composites (2005)

product development

lightweight applications / polymers and composites



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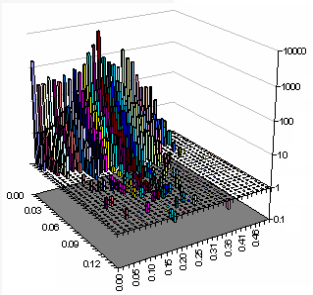

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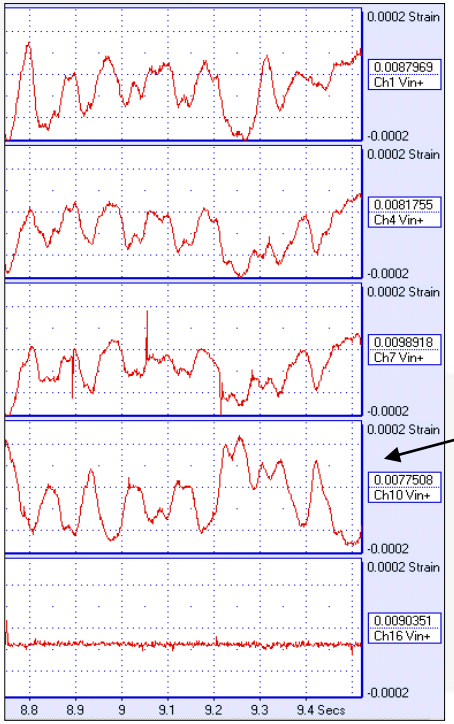
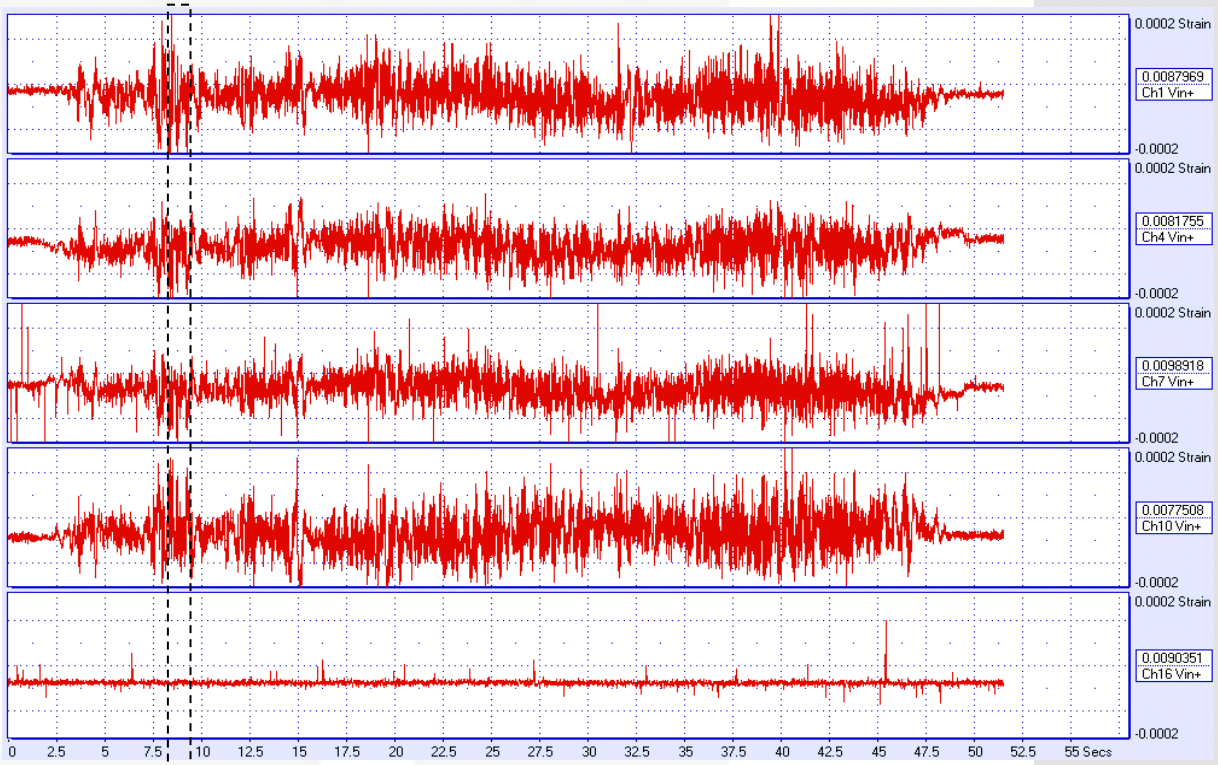
LH2 - tank suspension

realistic loads – e.g. bad gravel road

Movie driverposition

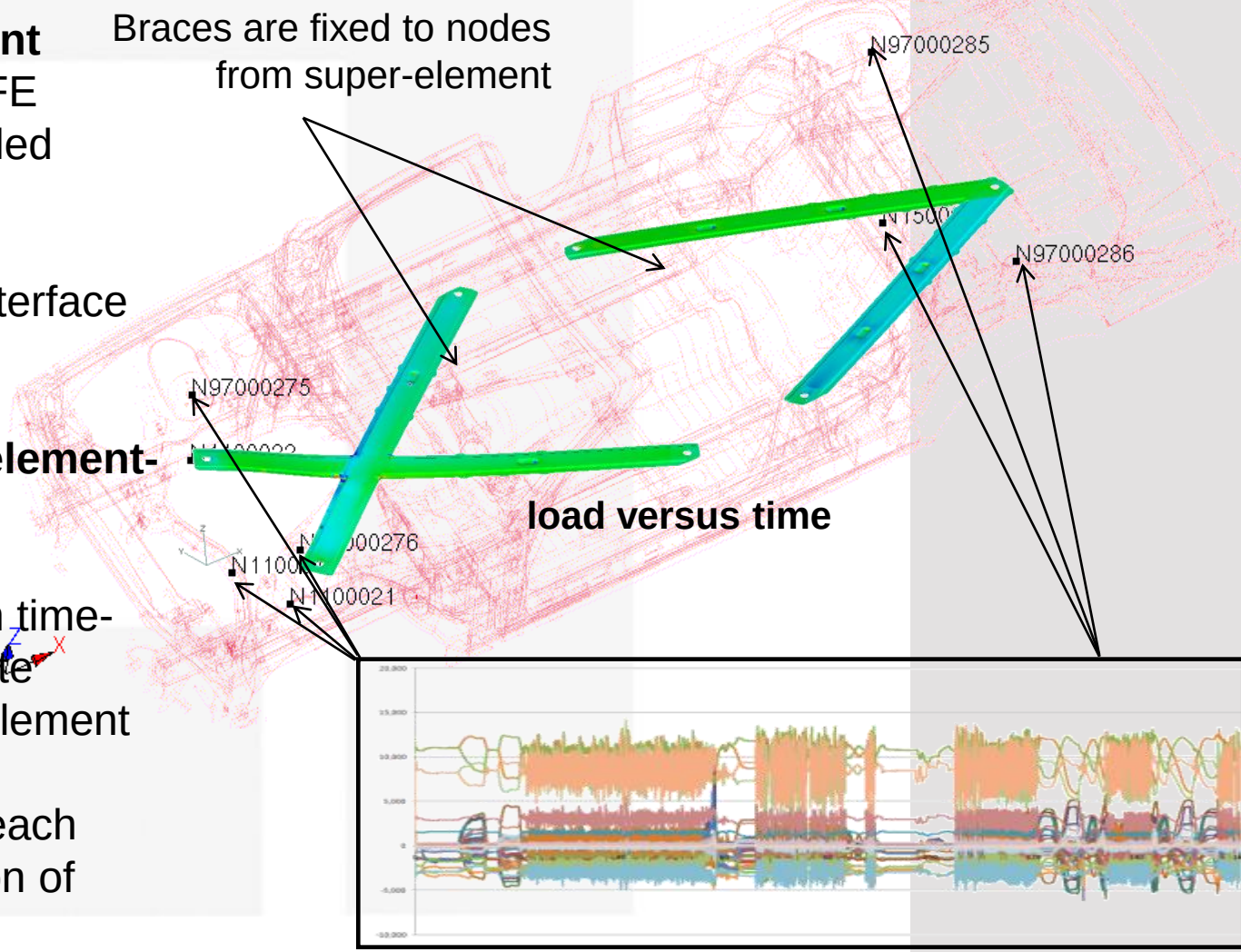




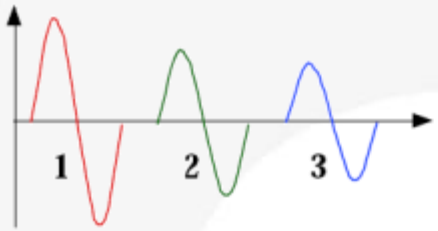
Strain versus time

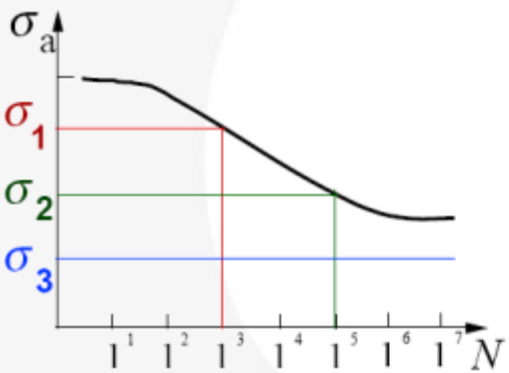
VX - Brace
complete FE-model (super-element)

- Use of a **super-element** (vehicle) for effective FE analysis – with a detailed modeling of the brace
- **Unit-loads** on each interface node in each direction
- Effect of unit-load on **element-stress** is known
- Superposition for each time-step to get the complete stress-state for each element
- **Laminate-theory** for each element and calculation of Failure (Puck´s law)



VX - Brace
damage accumulation





$$\sum_{i=1}^{I} \frac{n_i}{N_i} = \frac{500}{10^3} + \frac{10^3}{10^5} + \frac{10^4}{\infty} = 0.51 < 1$$

- Assume that, during the service life, we have 500 loadings of type **1** (defined by mid-value and magnitude), 1000 loadings of type **2** and 10000 loadings of type **3**
- The **Palmgren – Miner** rule states that **failure** occurs when

$$\sum_{i=1}^{I} \frac{n_i}{N_i} = 1$$

where n_i is the number of applied load cycles of type i, and N_i is the pertinent fatigue life

damage accumulation

$$D = \sum \frac{n_i}{N_i}$$

Original-Miner

$$S_a > S_{aD} : N = N_D \cdot \left(\frac{S_a}{S_{aD}}\right)^{-k}$$

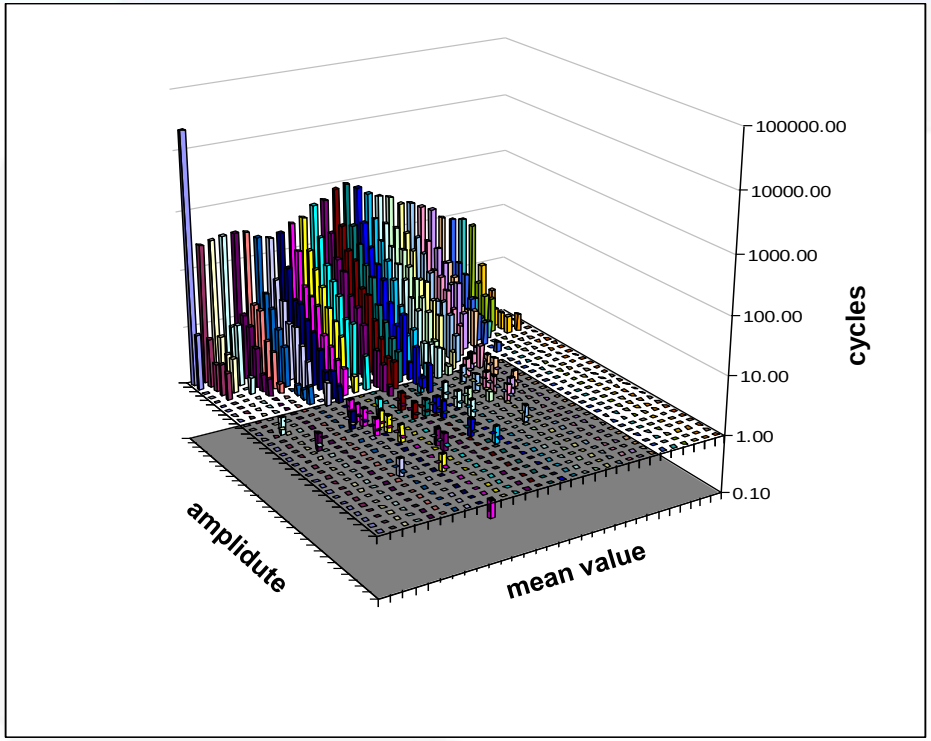
elementare Miner-Rule by Palmgren

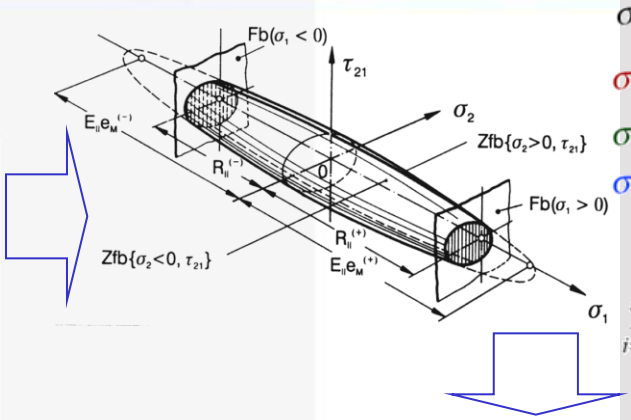
$$S_a <> S_{aD} : N = N_D \cdot \left(\frac{S_a}{S_{aD}}\right)^{-k}$$

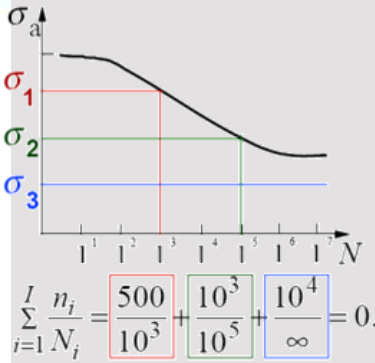
Miner-Rule modifized by Haibach

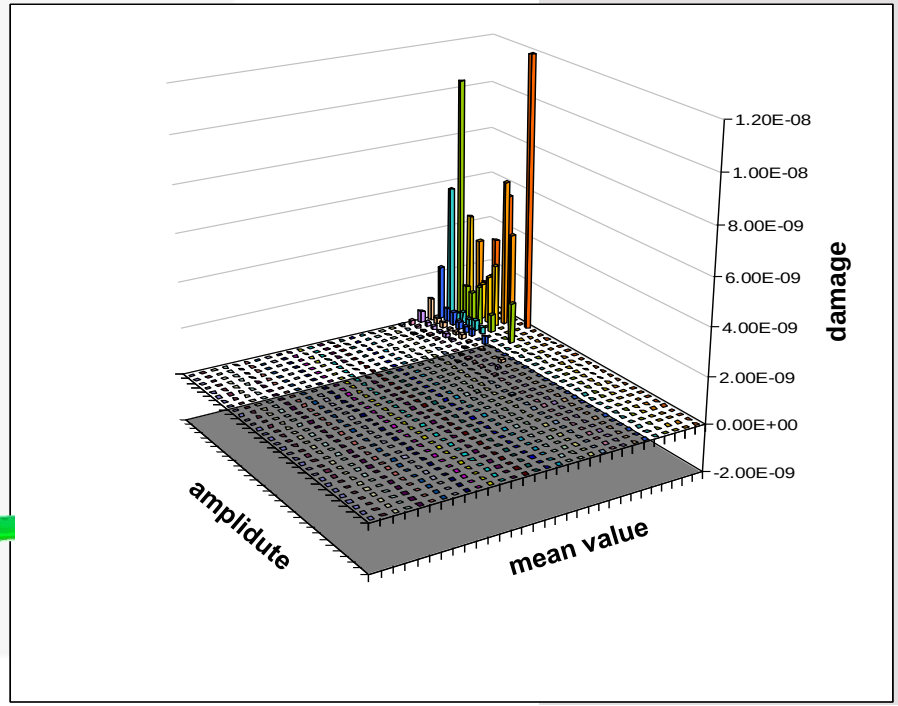
$$S_a \leq S_{aD} : N = N_D \cdot \left(\frac{S_a}{S_{aD}}\right)^{-(2k-1)} \quad S_a > S_{aD} : N = N_D \cdot \left(\frac{S_a}{S_{aD}}\right)^{-k}$$

VX - Brace
a critical Element - loadcase R1

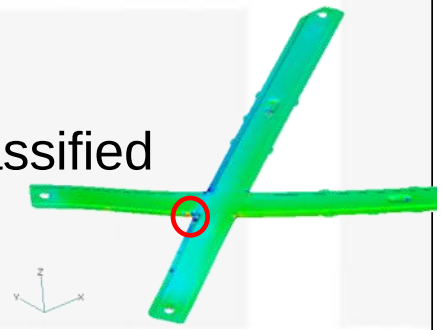






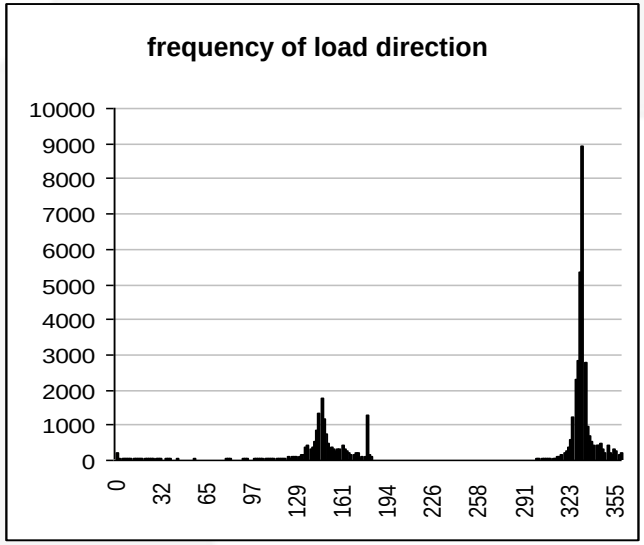


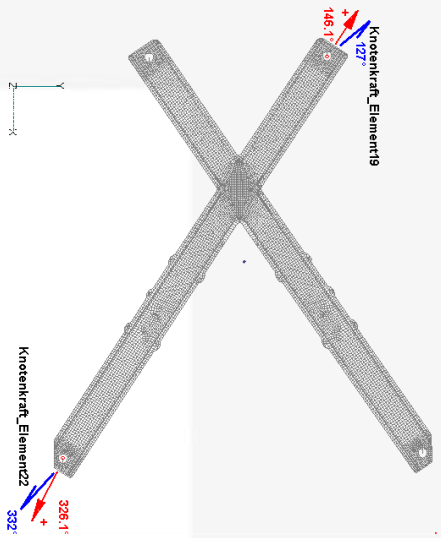
Number of cycles, classified by **rainflow analysis**

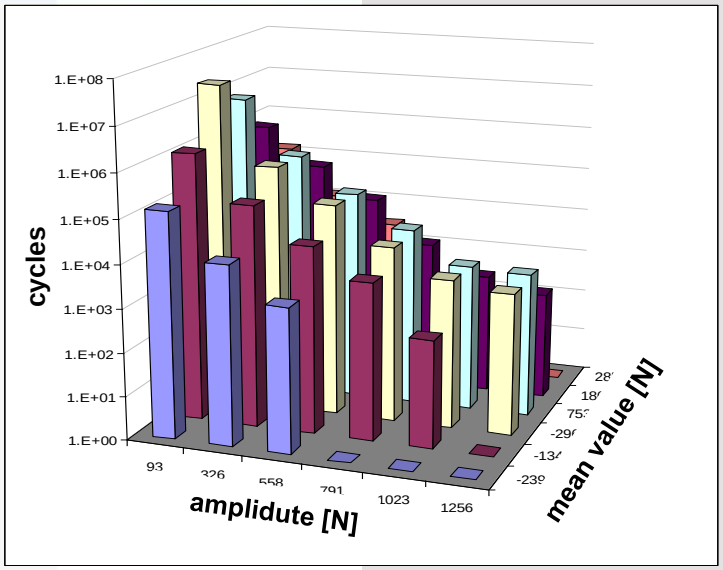


Total damage after 575 rounds → **3.75E-01**

VX - Brace
parameters for component tests







cracks short before end of test (n=87654, +/-10kN)

Fatigue of composite parts
Zusammenfassung und Ausblick

- Einfluss auf Lebendauer
  - Faserorientierung kann durch normieren eliminiert werden
  - Temperatur und R-Verhältnis beeinflussen Lebensdauer
- Lastumlagerungsvorgänge haben Vorschädigungen und Kerben geringeren Einfluss im Vergleich zu metallische Werkstoffen
- Off-axis Fatigue von UD-Verbunde deutlich unterschiedlich zu Gewebe-Verbunde
- Betriebsfestigkeitsberechnung
  - Superelement mit Einheitslasten
  - Rainflowanalyse der Faserlängs- und Querspannungen
  - Lineare Schadenakkumulation – Puck‘s Versagenshypothese
- Nicht untersucht wurden Energiedissipation, Lastzeitfolge, Alterung

Vielen Dank für Ihre Aufmerksamkeit!