Lebensdauerabschätzung von Faserverbundbauteilen

DI Martin Fritz, DI Peter Reithofer, DI Pichler Michael

Die auftretenden Versagensmechanismen und die zugeordneten ertragbaren Lastspiele werden bei Faserverbundbauteilen von zahlreichen Faktoren beeinflusst.
Lokale Faserorientierung und Faseranteil, Umgebungseinflüsse wie Temperatur und Feuchte, chemische und physikalische Alterungsvorgänge, mögliche Energiedissipationen oder herstellungsbedingte Eigenspannungen können die Lebensdauer maßgeblich verkürzen.

Umso wichtiger ist daher, die Berücksichtigung der wesentlichen Einflussfaktoren in der Prozesskette und die Verwendung hinreichend geeigneter Versagenshypothesen bei der virtuellen Lebensdauerabschätzung von Faserverbundbauteilen.

Anhand von Anwendungsbeispielen aus der Automobilindustrie wird die Vorgehensweise erläutert und Effekte werden diskutiert.

Fatigue of composite parts

The occurring failure modes and their dedicated tolerated number of load cycles of composite parts are influenced by many parameters.

Parameters like fiber-orientation und fiber-content, environmental conditions such as temperature and humidity, chemical and physical aging, dissipation of energy and residual stresses emerging during the production process have a wide impact on the fatigue life of composite parts.

Therefore it is very important to consider the main influencing factors and to find an adequate failure criterion for the virtual fatigue-prediction of composite parts.

The principal method and the occurring effects are shown on the basis of examples from the automotive industry.

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Lebensdauerabschätzung von Faserverbundbauteilen

(fatigue of composite parts)

M. Fritz, P. Reithofer (4a engineering GmbH, Traboch- A)

9. LS-DYNA Forum 2010

12.-13. Oktober 2010, Bamberg

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I N P H Y S I C S W E T R U S T

group of companies

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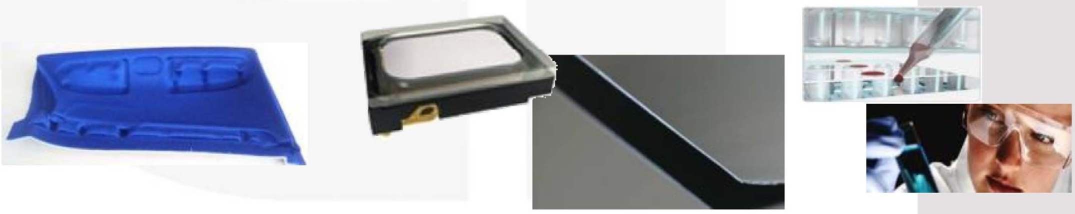

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I N P H Y S I C S W E T R U S T

product development
lightweight applications / polymers and composites

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…is this predictable?

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product development
lightweight applications / polymers and composites

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MAGNA STEYR ENGINEERING

IVM Automotive
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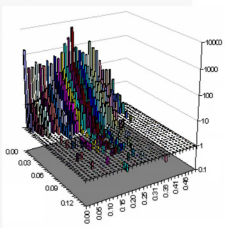

LH_2 – inner tank suspension
lowest possible heat transfer / BMW clean energy
high stiffness, high strength composite solution
increased performance : 250%

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

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example: development LH2 - tank suspension

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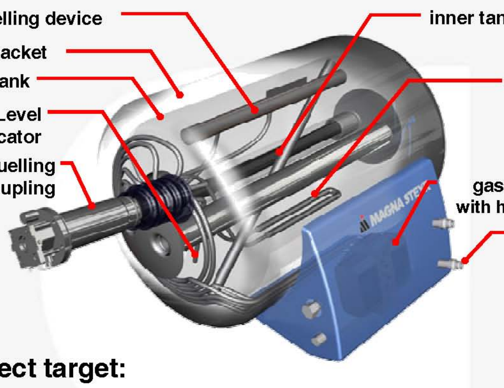
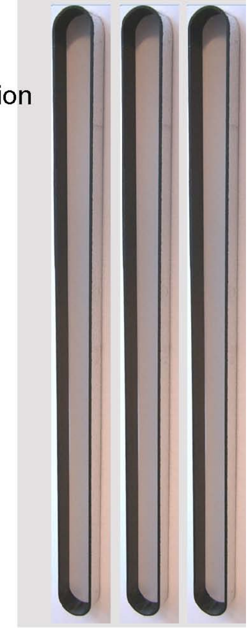


reasons for using composites:

- 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

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LH2 - tank suspension defining test setups

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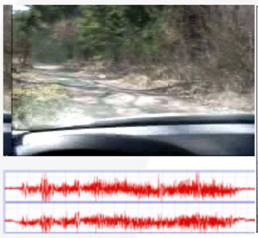
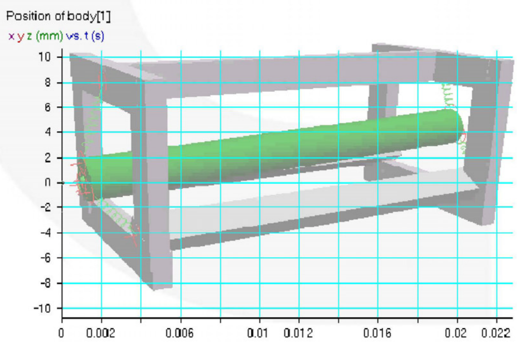
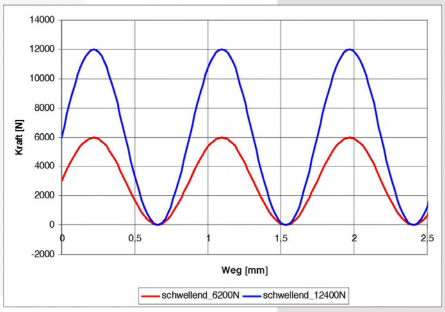
tests on bad gravel roads



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



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LH2 - tank suspension equipment and test setup

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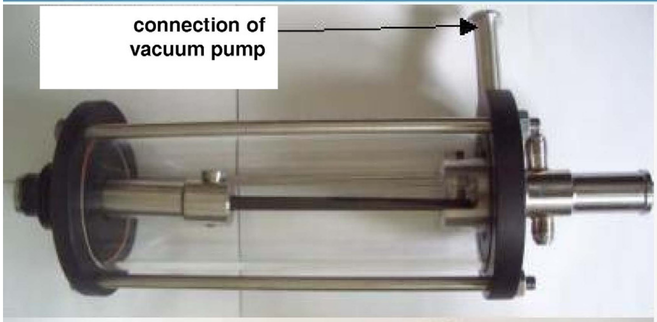
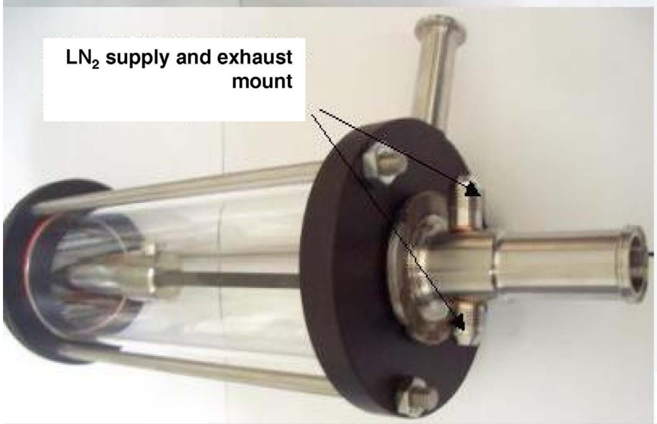




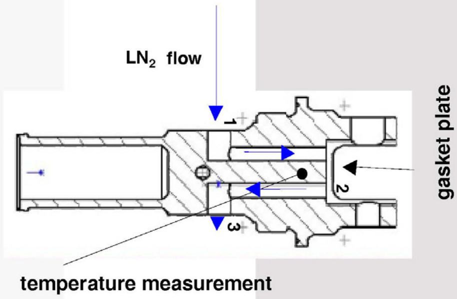
realistic test setup

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

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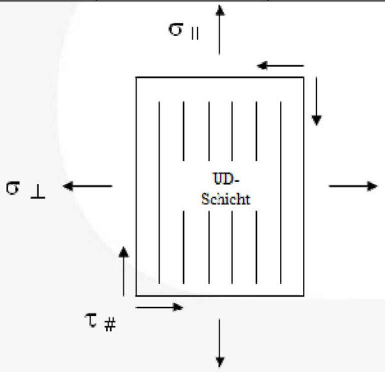
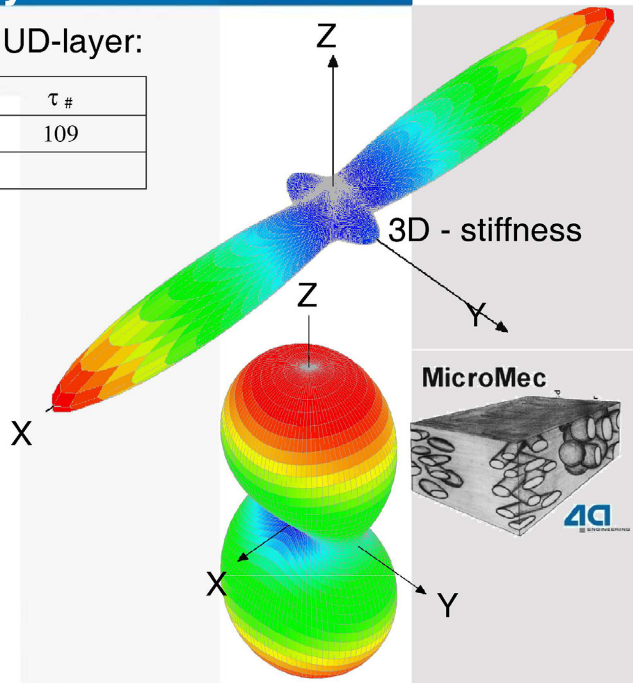
LH2 - tank suspension
CFRP – unidirectional Layer

Typical strenght values of a CRFP - UD-layer:

IM7/977	σ ‖	σ ⊥	τ #
Zug	1430	36	109
Druck	-900	-218	



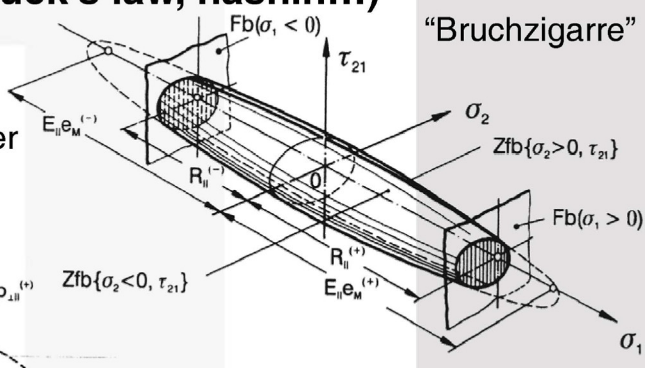
- 2-D ply stress
- local coordinating system
- τ^{ils} interlaminar shearstrenght

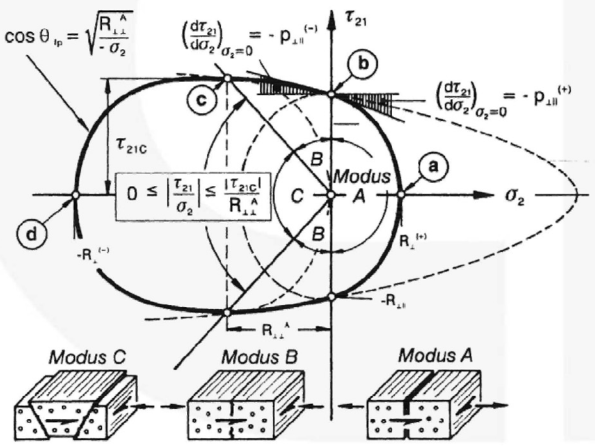


LH2 - tank suspension
puck's law

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

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





- matrix-failure mode :
  tension
  shear
  "Sprengbruch"
- also for 3D stress states are covered

LH2 - tank suspension
modeling the fatigue-strength

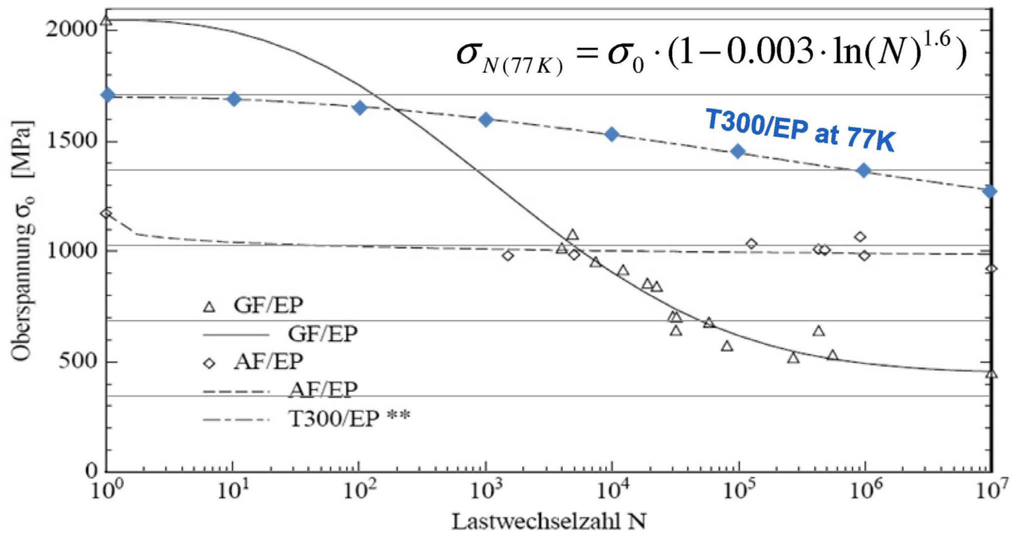


Abbildung 5.8: σ_o–N Diagramm verschiedener UD Verbunde unter schwellender Zugbelastung bei 77 K; R=0,1

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

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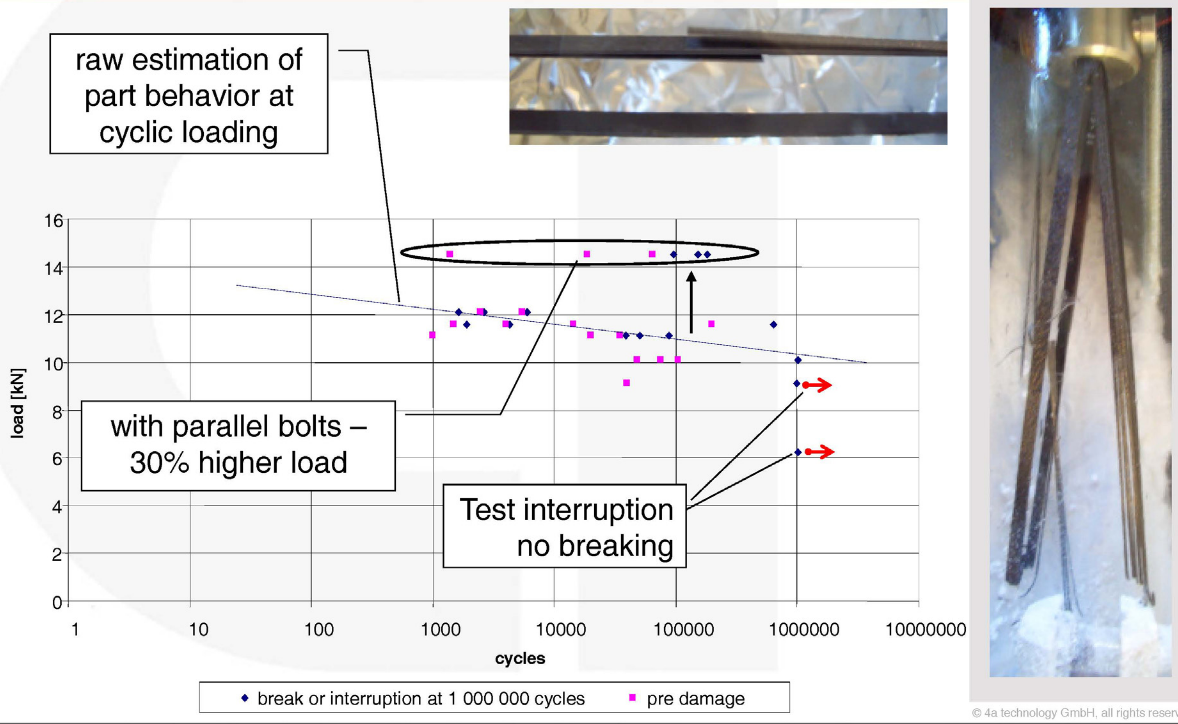
LH2 - tank suspension
cyclic loading at 77K



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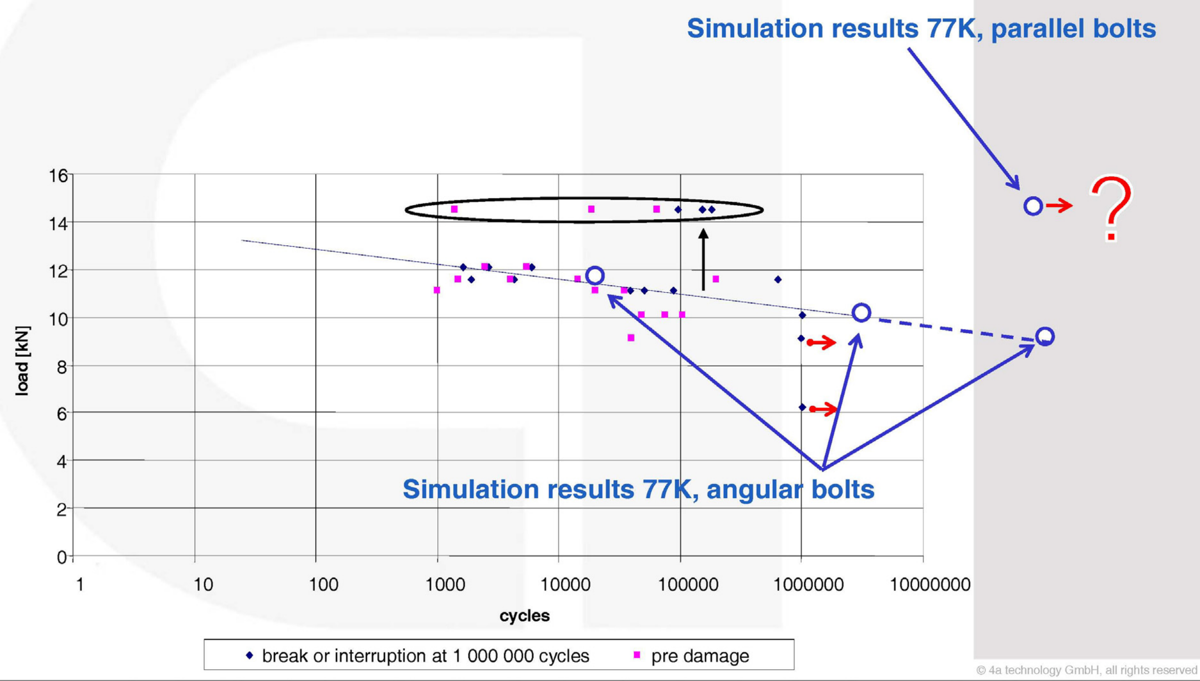
LH2 - tank suspension
prediction of load cycles



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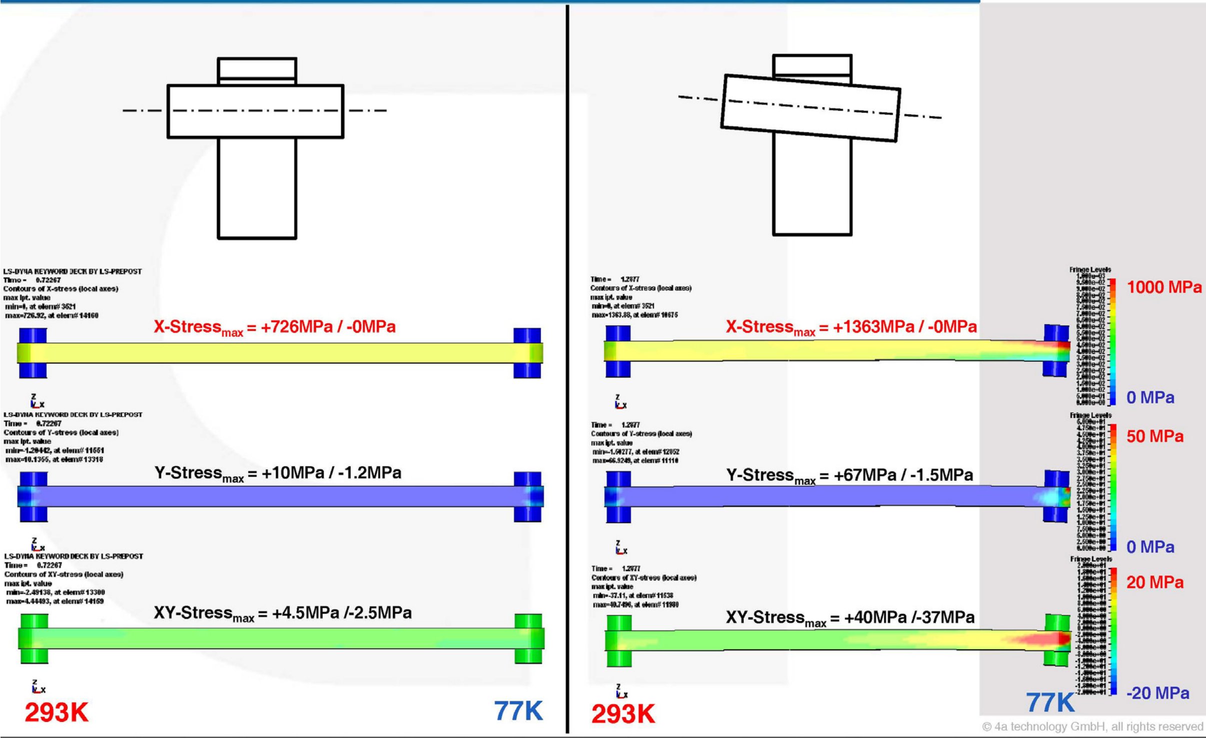
LH2 - tank suspension
simulation - parallel bolt position (at 10kN)



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LH2 - tank suspension
S-N-curves, effect of temperature

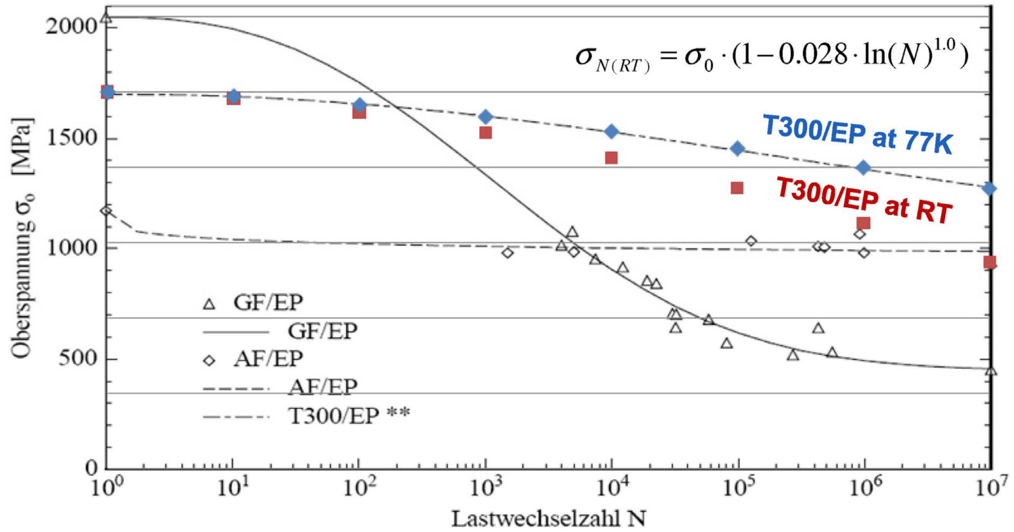
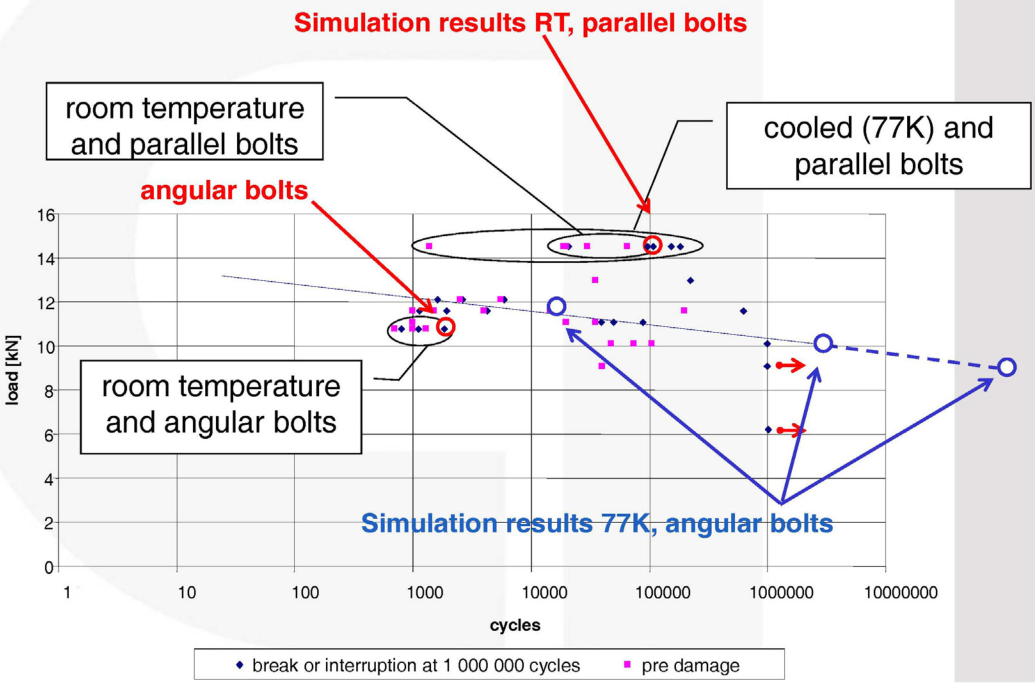


Abbildung 5.8: σ_o–N Diagramm verschiedener UD Verbunde unter schwellender Zugbelastung bei 77 K; R=0,1

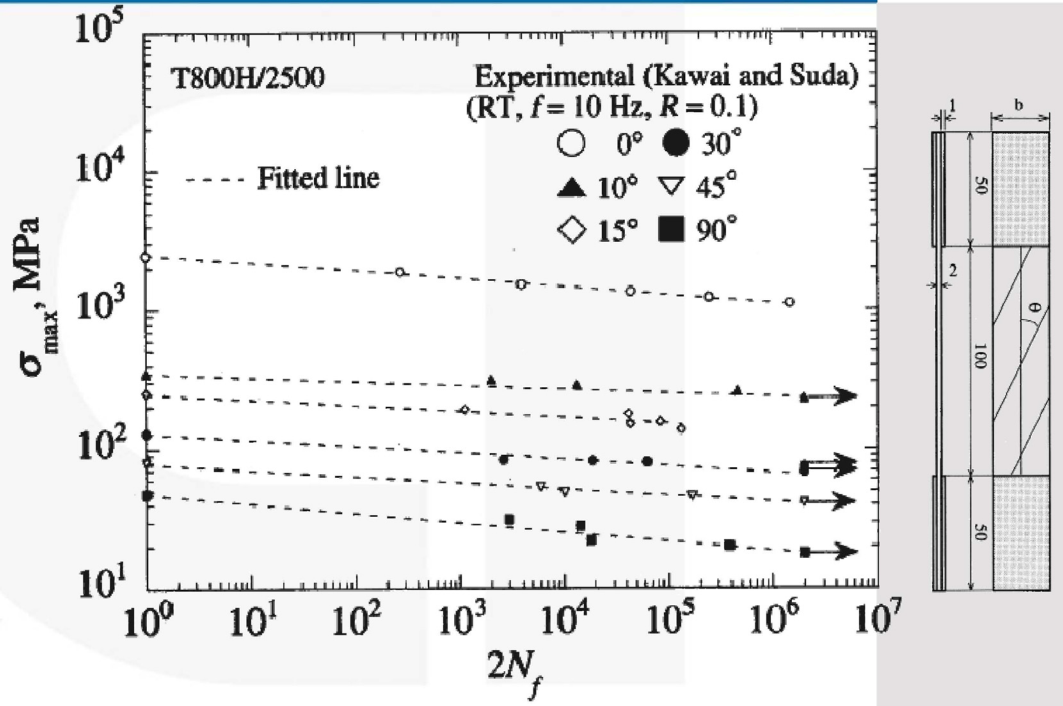
**) aus [Pannkoke 92], S. 68

LH2 - tank suspension
comparison with simulation results



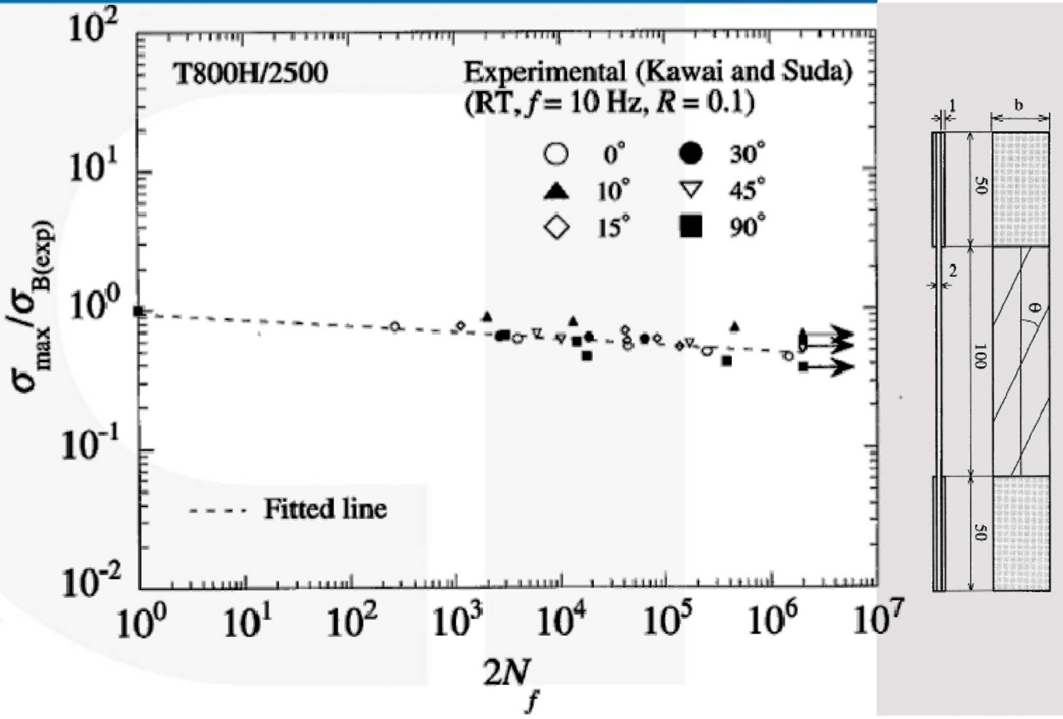
LH2 - tank suspension

effect of stress ratio (e.g. CFRP)

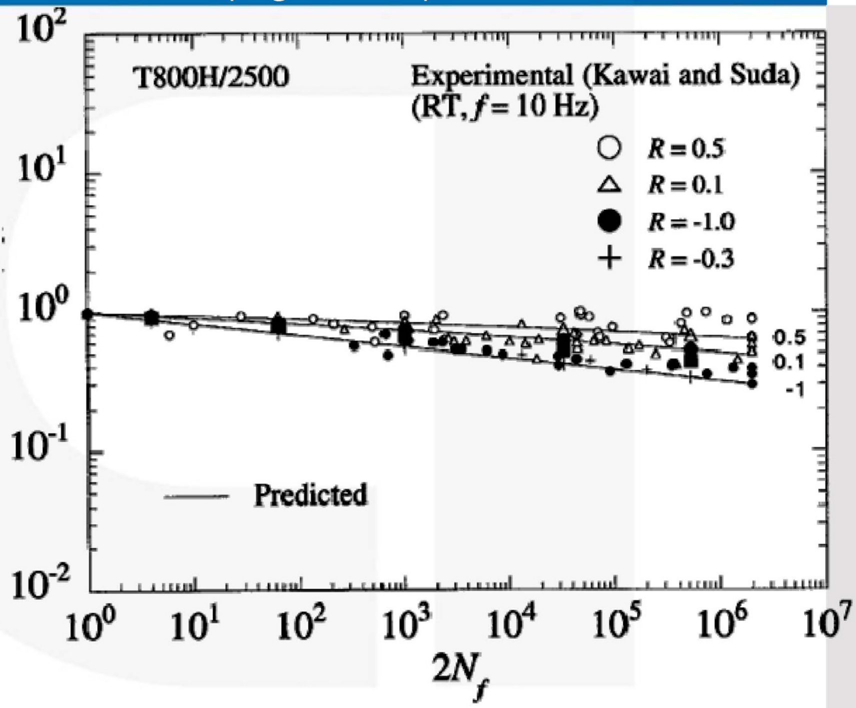


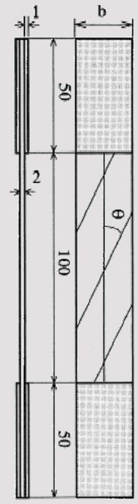
LH2 - tank suspension

effect of stress ratio (e.g. CFRP)



LH2 - tank suspension
effect of stress ratio (e.g. CFRP)





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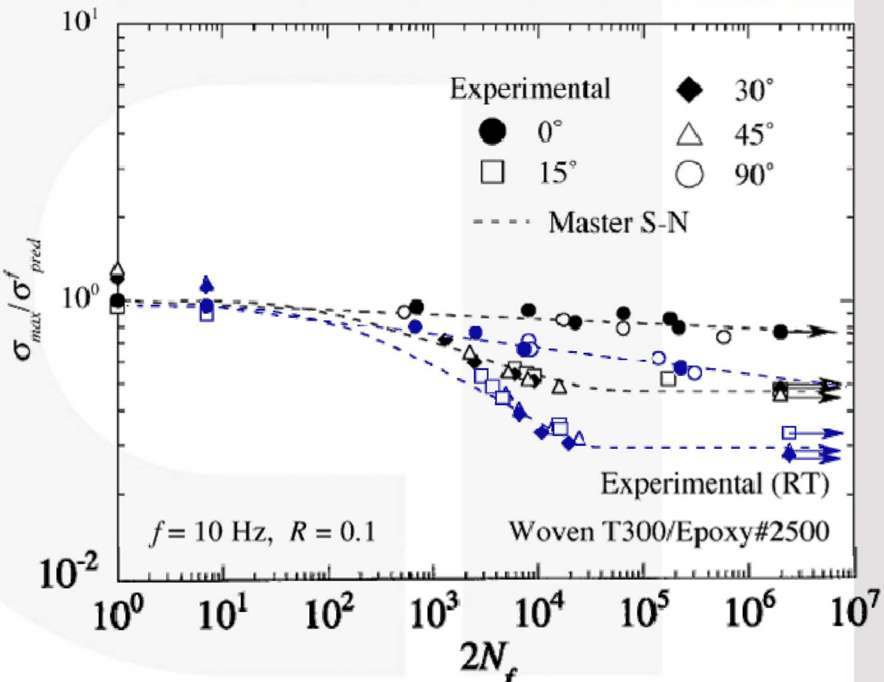
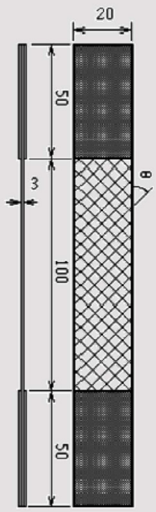
LH2 - tank suspension
effect of off- axis load on fatigue behaviour





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

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product development
lightweight applications / polymers and composites

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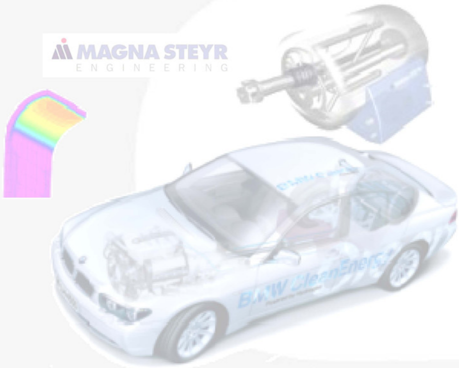
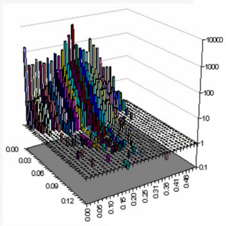


LH_2 – inner tank suspension
lowest possible heat transfer / BMW clean energy
high stiffness, high strength composite solution
increased performance : 250%

IVM Automotive
Member of Edscha Group



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

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LH2 - tank suspension
realistic loads – e.g. bad gravel road

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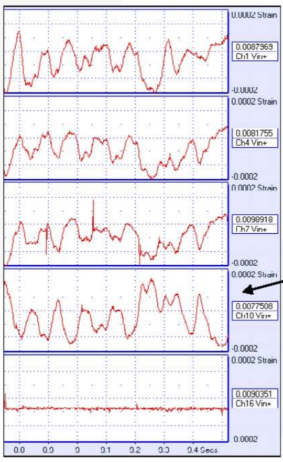
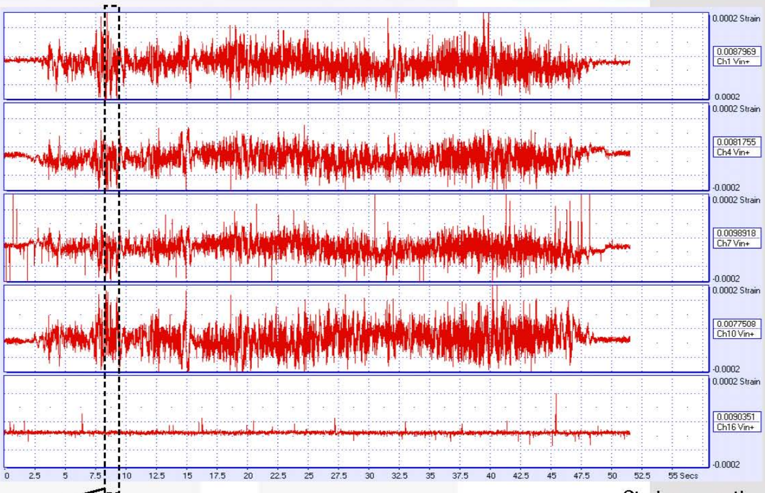
Movie driverposition





Strain versus time

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I N P H Y S I C S W E T R U S T

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

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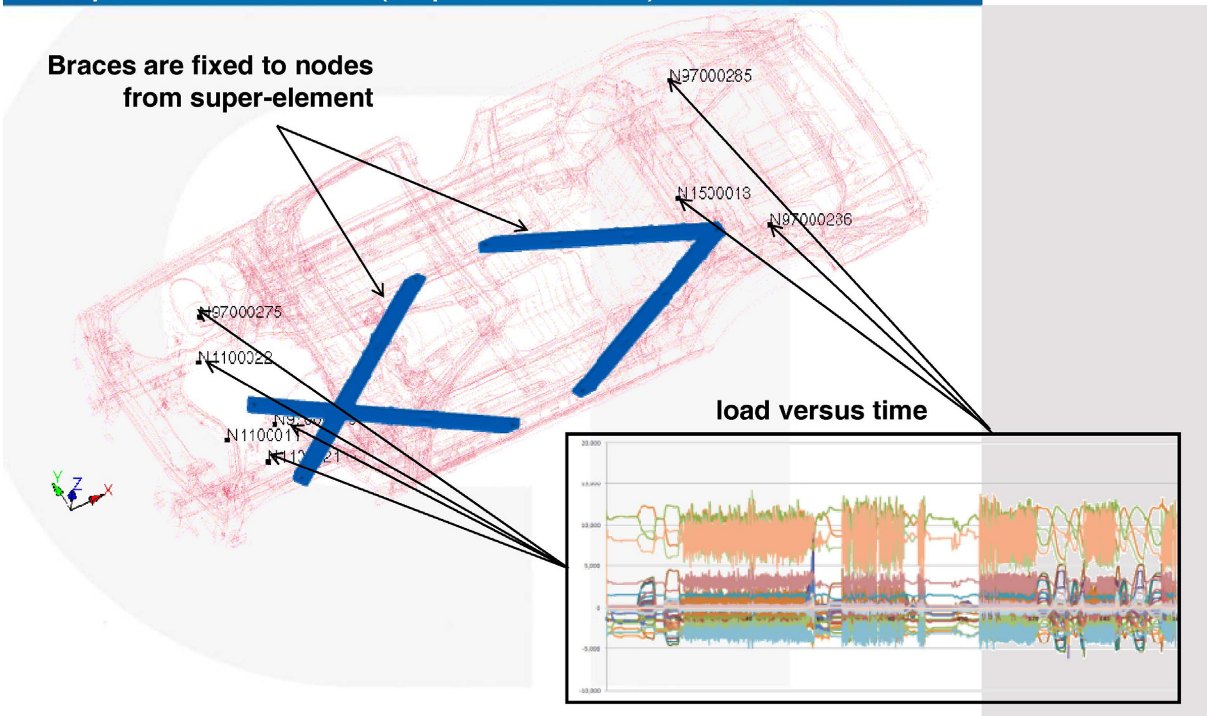

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VX - Brace
critical regions (fiber failure)

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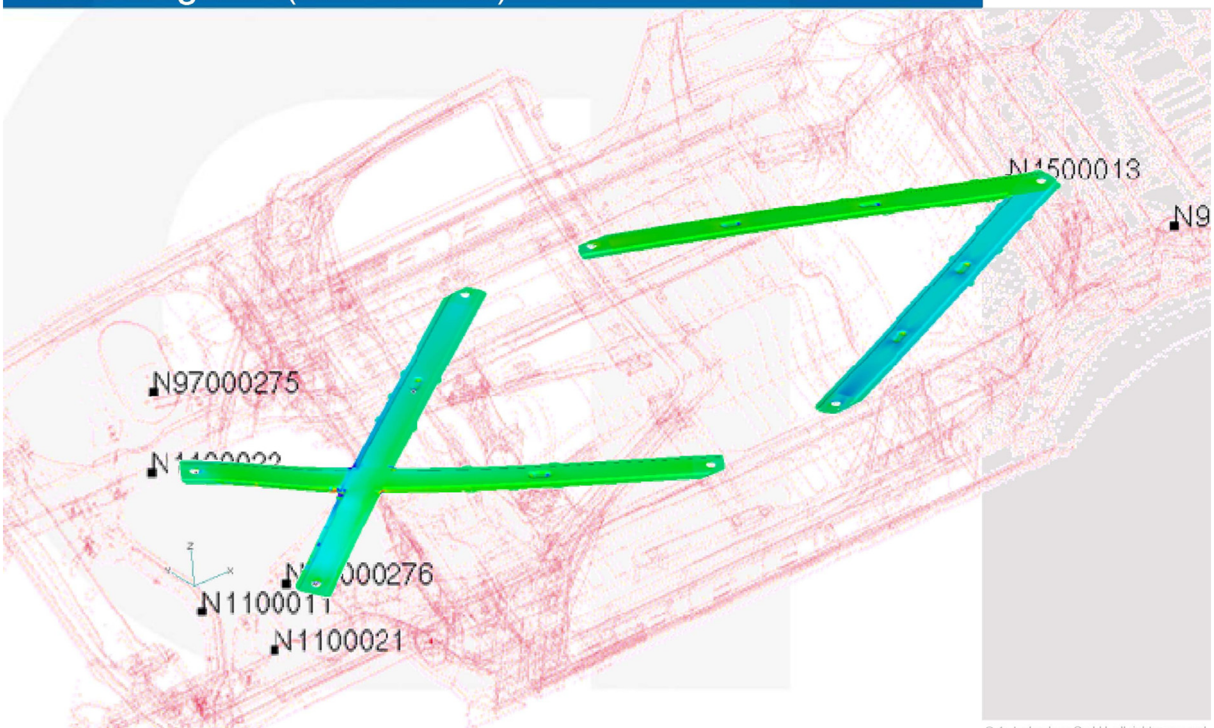

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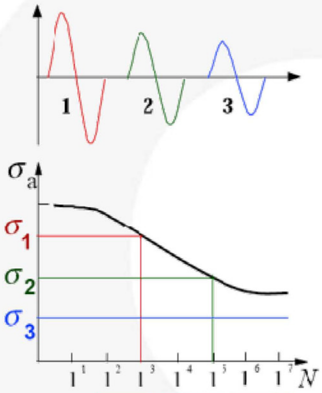
VX - Brace
damage accumulation



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

- 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

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

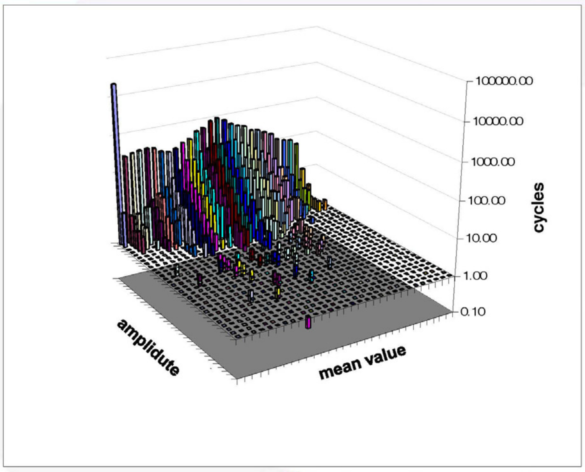
elementare Miner-Rule by Palmgren

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

Miner-Rule modified by Haibach

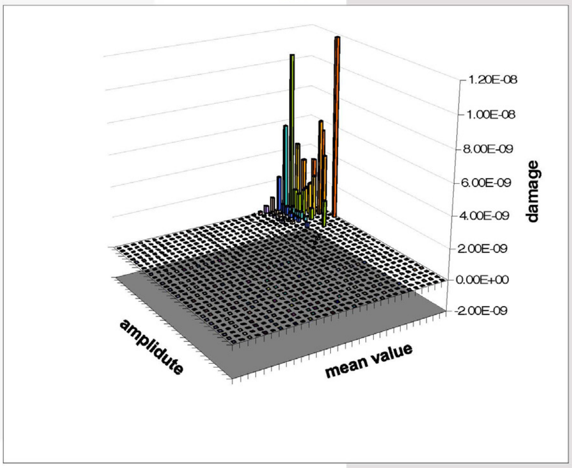
$$S_a \leq S_{aD} : N = N_D \cdot \left(\frac{S_a}{S_{aD}}\right)^{-(2k-1)} \quad S_a > S_{aD} : N = N_D \cdot \left(\frac{S_a}{S_{aD}}\right)^{-k}$$

VX - Brace
a critical Element - loadcase R1



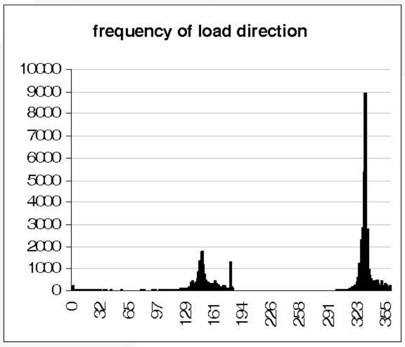
Number of cycles, classified by rainflow analysis in mean values and amplitudes of damage (Puck's law)

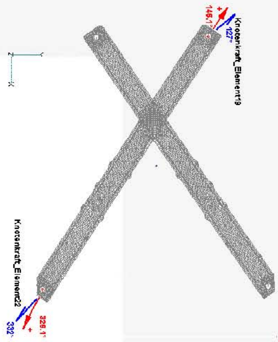
total damage, classified by rainflow analysis in mean values and amplitudes of damage (Puck's law)

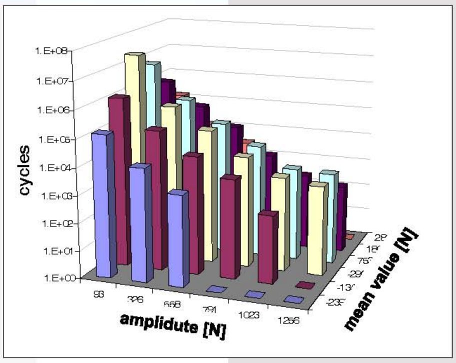


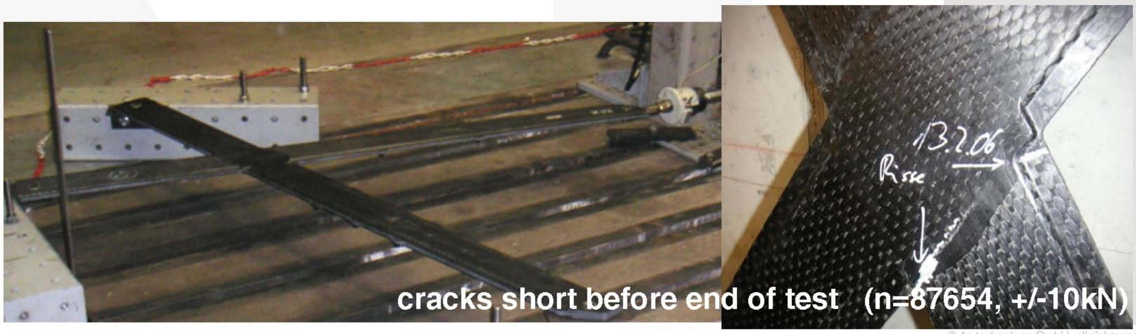
Total damage after 575 rounds → **3.75E-01**

VX - Brace
parameters for component tests





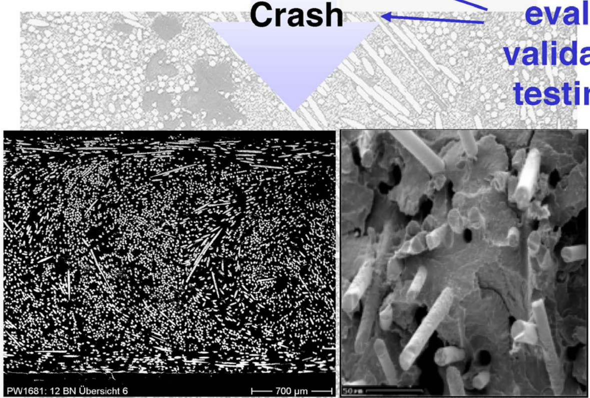




vision - virtual estimation from process to break

Design
Process
complete virtual estimation Stiffness especially for polymer components
Strength
Crash

physical models
evaluation and validation by new testing methods



in physics we trust ...

