

# Zeitabhängiges Materialverhalten von Kunststoffen

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- Einleitung
  - An- / Herausforderungen
- Dynamische Materialcharakterisierung
  - 4a impetus – Working Process
  - Themenwolke
- Statisches Verhalten
- Langzeitverhalten
  - Kriechen
  - Alternatives Konzept
- Zusammenfassung

# Einleitung

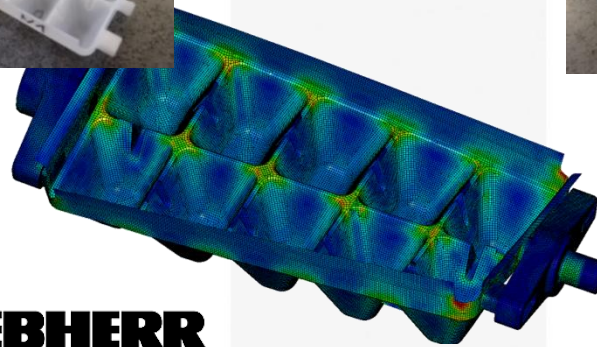
## Zeitabhängiges Verhalten



Quelle: <http://mobiwatch.de>



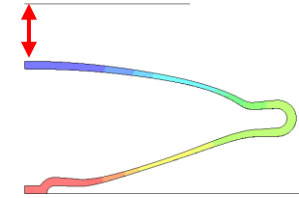
**LIEBHERR**



**FLEXIMA**  
feel the comfort.at

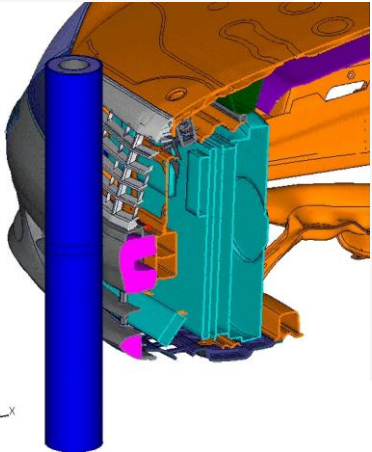
3 Tage

9.8 mm

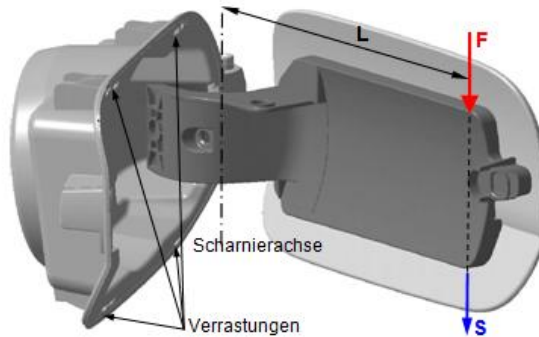


Quelle: [Wimmer, TT 2012](#)

**μs      ms      s      min      h      t      w      y**



Quelle: [Kolling, TT 2010](#)

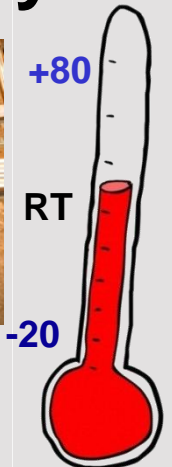


Quelle: [Gramling, TT 2012](#)



Quelle:

<http://www.rad-ab.com/tag/opel-astra/>



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# Einleitung

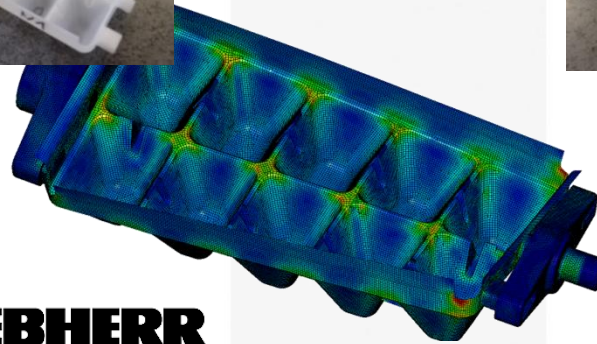
## Zeitabhängiges Verhalten



Quelle: <http://mobiwatch.de>



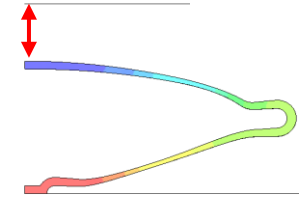
**LIEBHERR**



**FLEXIMA**  
feel the comfort.at

3 Tage

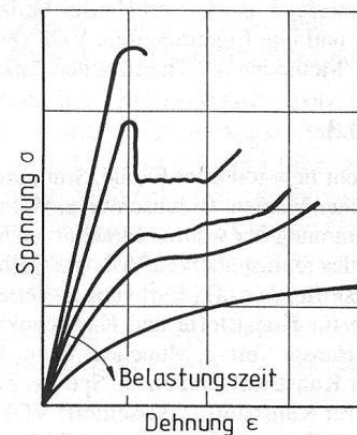
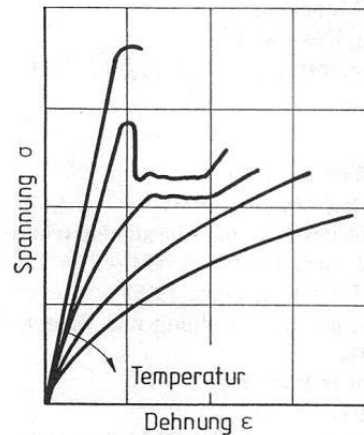
9.8  
mm



Quelle: [Wimmer, TT 2012](#)



$\mu$ s      ms      s      min      h      t      w      y



Quelle: <http://www.mhaeberl.de>

# Einleitung

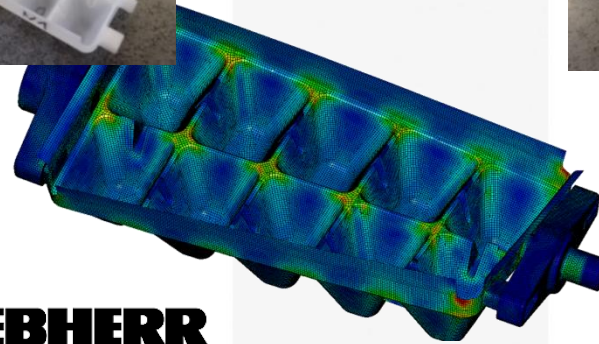
## Zeitabhängiges Verhalten



Quelle: <http://mobiwatch.de>



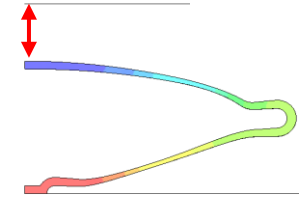
**LIEBHERR**



**FLEXIMA**  
feel the comfort.at

3 Tage

9.8 mm



Quelle: [Wimmer, TT 2012](http://Wimmer, TT 2012)

$\mu$ s

ms

s

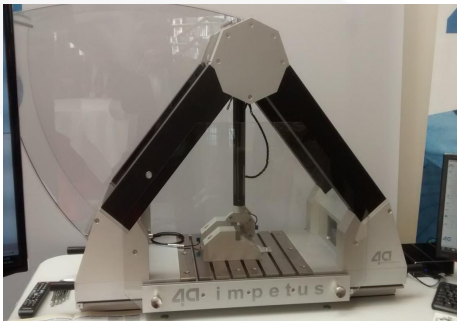
min

h

t

w

y



Quelle: <http://www.directindustry.de>



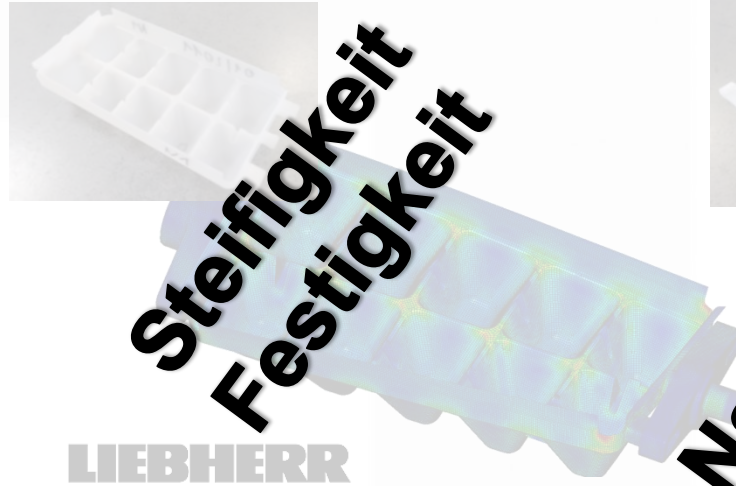
Quelle: <http://products.coesfeld.com>

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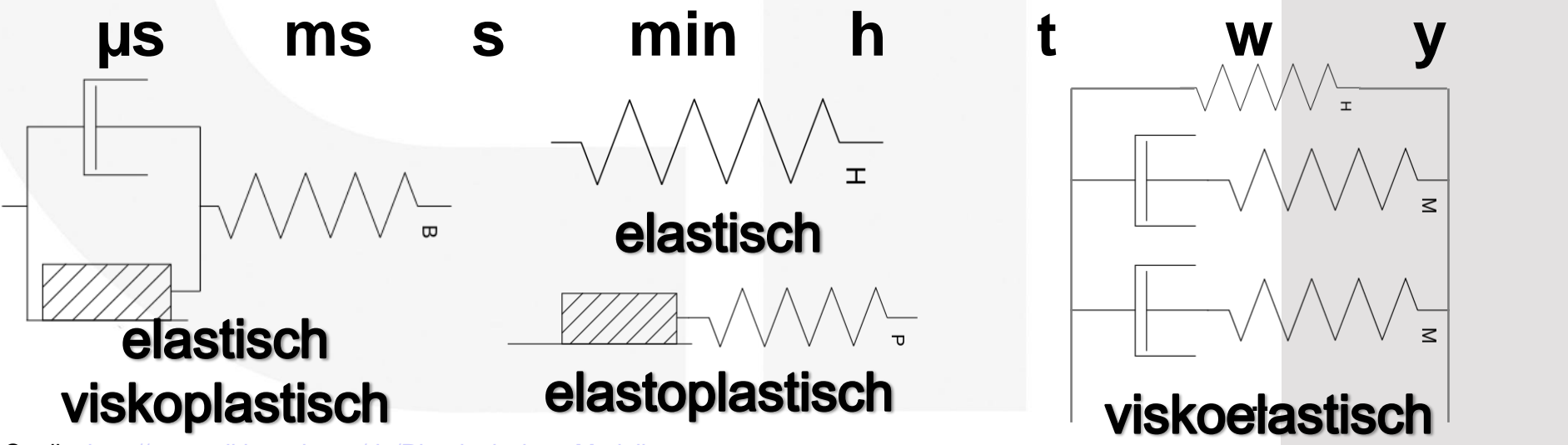
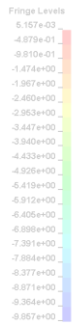
# Einleitung

## Zeitabhängiges Verhalten

**Energie-  
aufnahme  
Versagen**

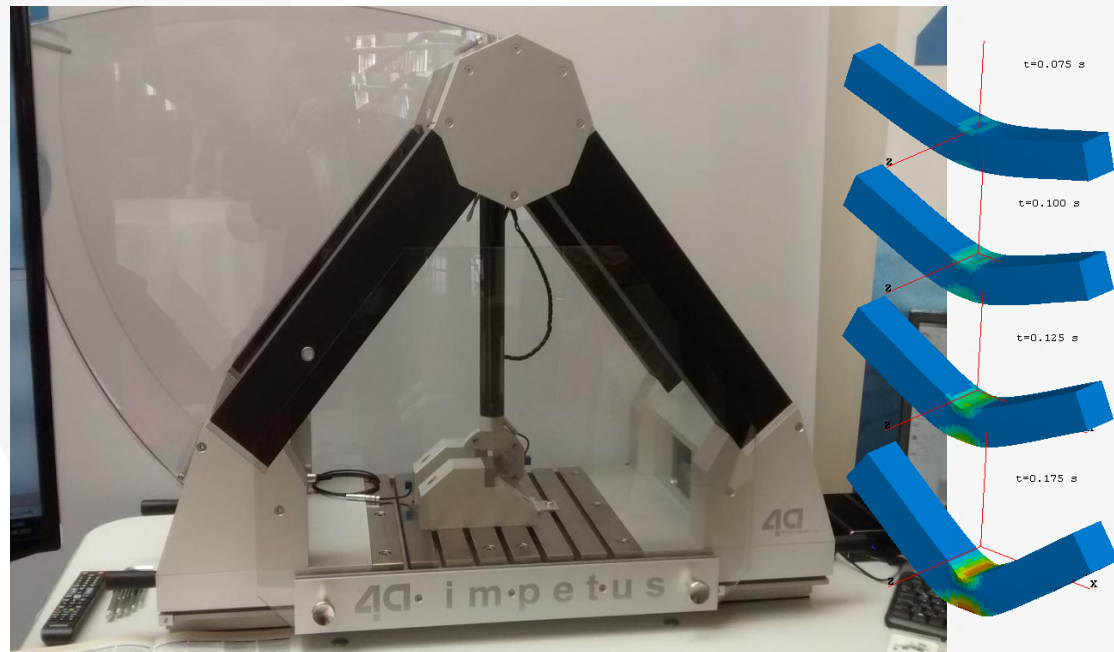


LIEBHERR

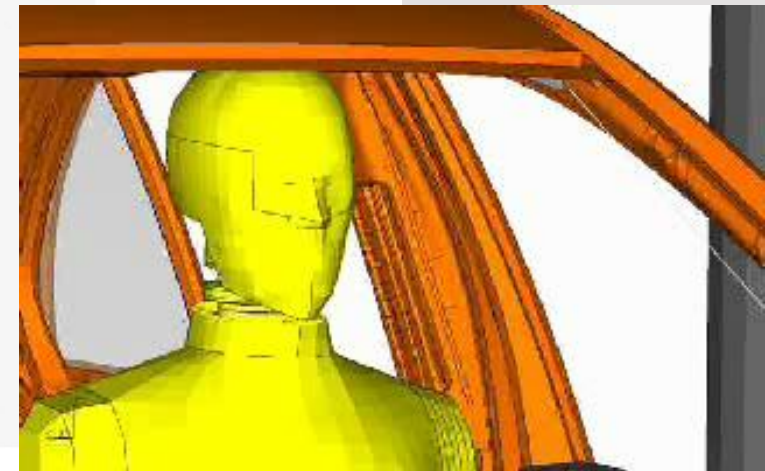


Quelle: [http://www.wikiwand.com/de/Rheologisches\\_Modelle](http://www.wikiwand.com/de/Rheologisches_Modelle)

- efficient high-dynamic testing
- crash-behaviour of plastics
- material data for simulation



Quelle: <http://gm-volt.com/>



Quelle: [Dynamore](#)

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**4a impetus - intelligent testing systems  
powered by 4a engineering GmbH**

# Dynamische Materialcharakterisierung

## Software solution from the test to the material card

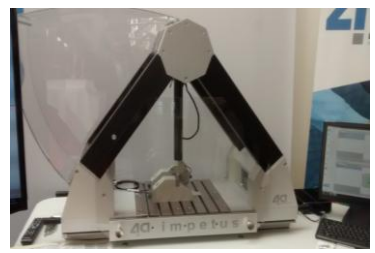
static

External Testing

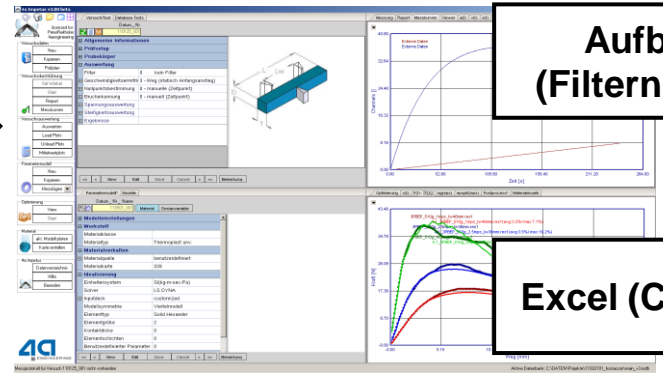


dynamic

4a impetus Hardware



4a impetus Software



Aufbereite  
(Filtern, Statistik)

Excel (Copy/F)

Powerpoi  
Template

Automatic\*

Reverse  
Engineering

Optimierer



Testresults



Reports

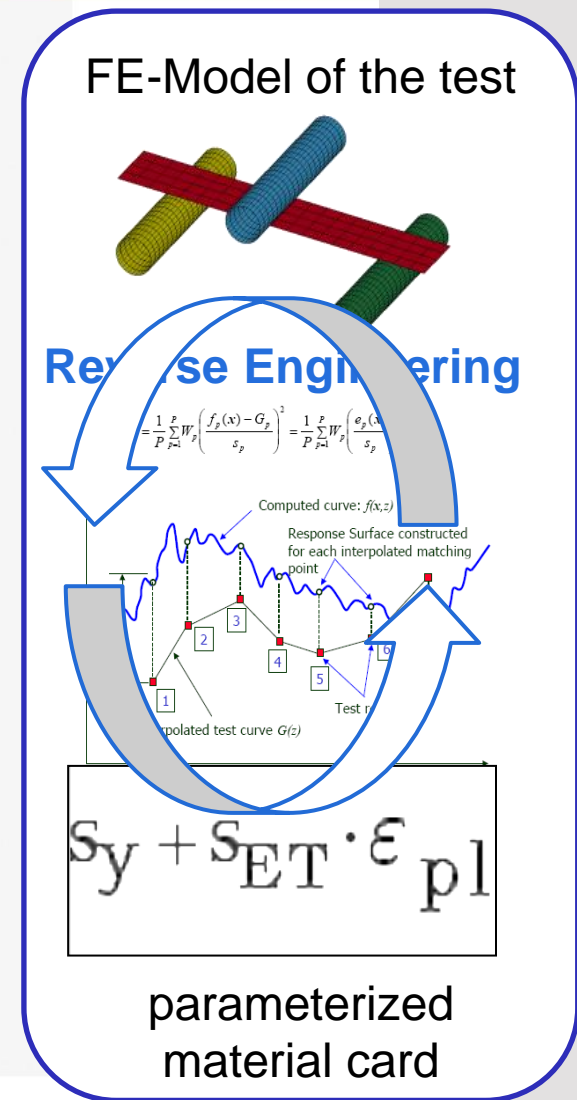
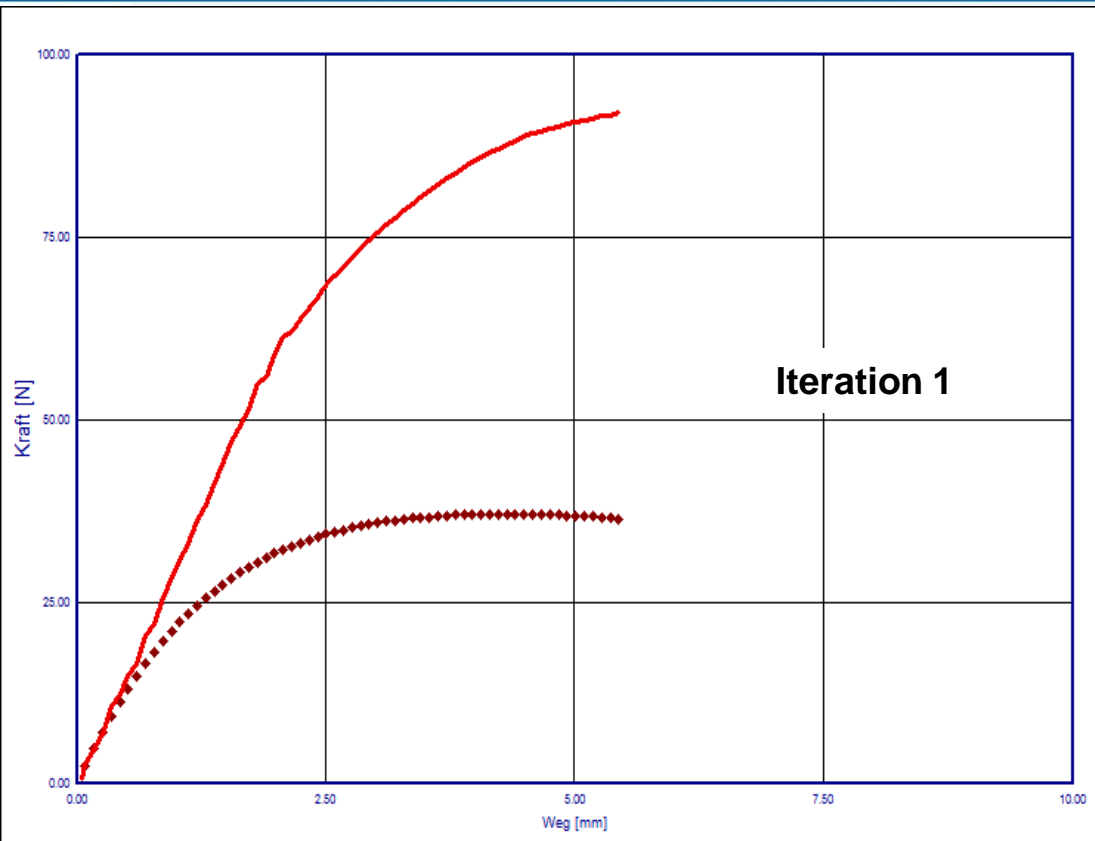


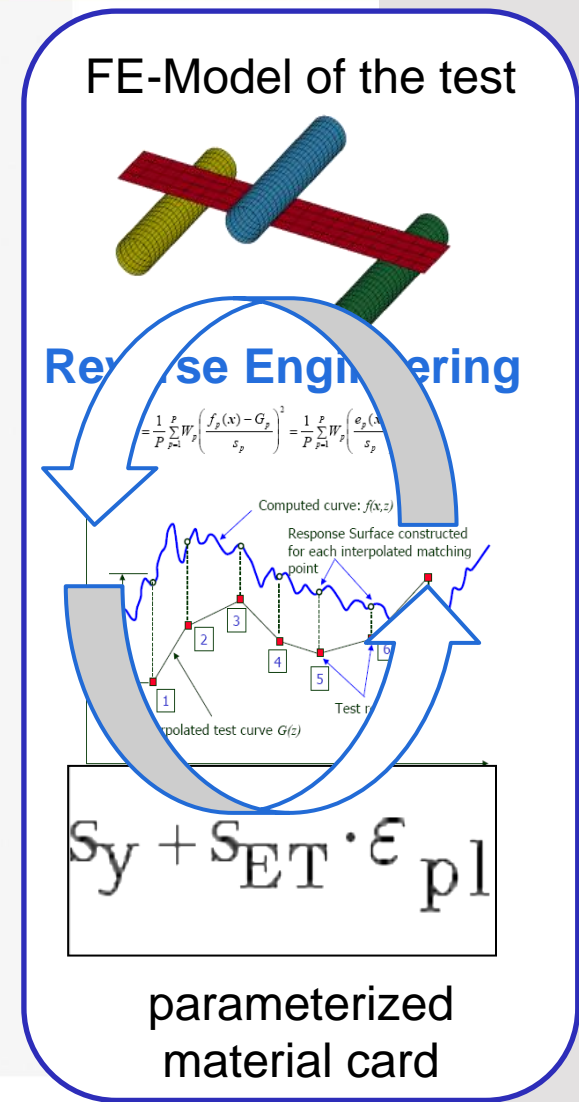
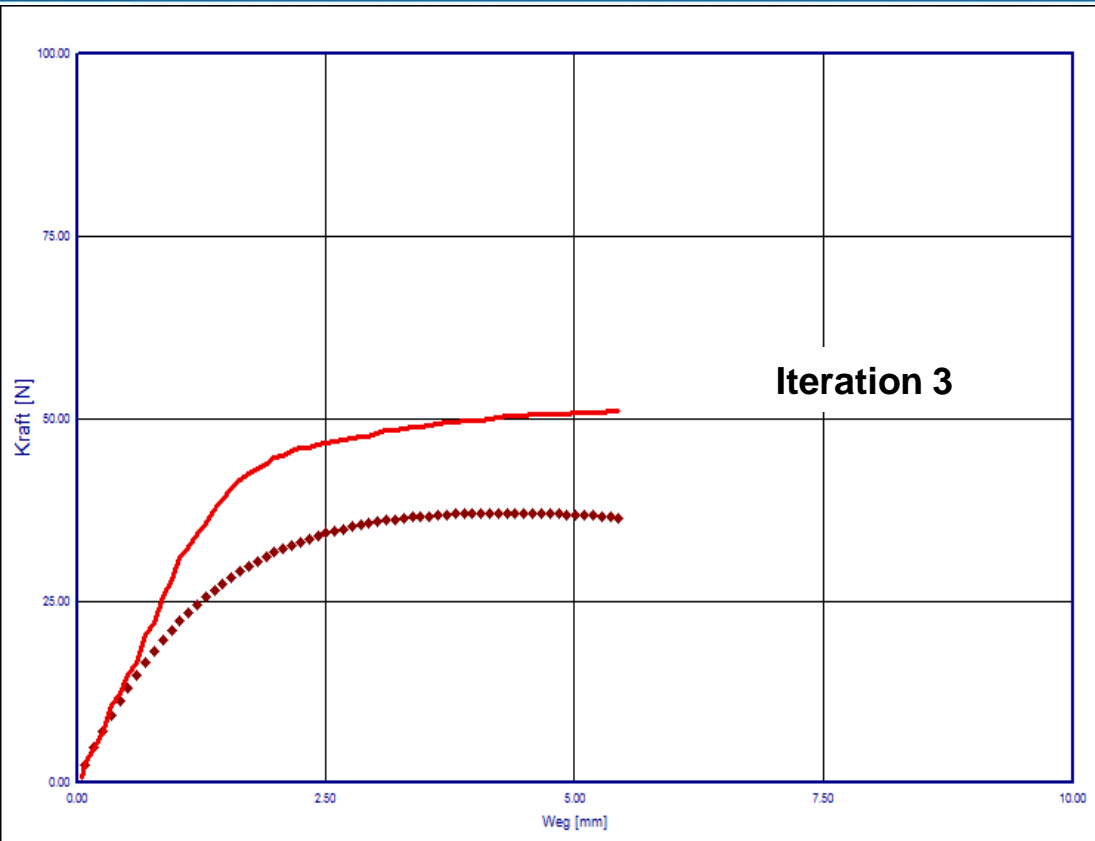
Workflow

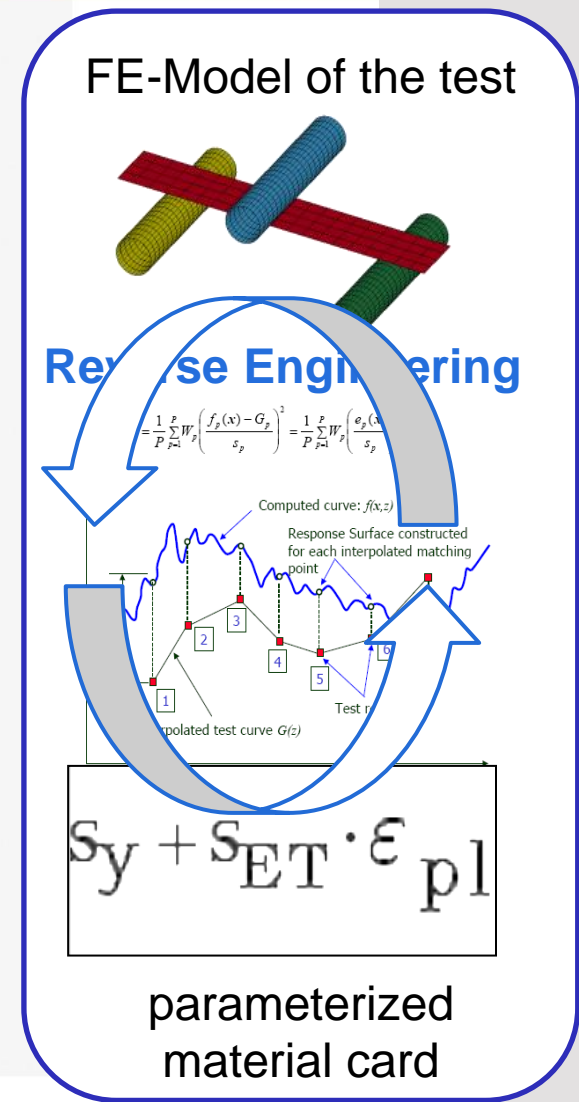
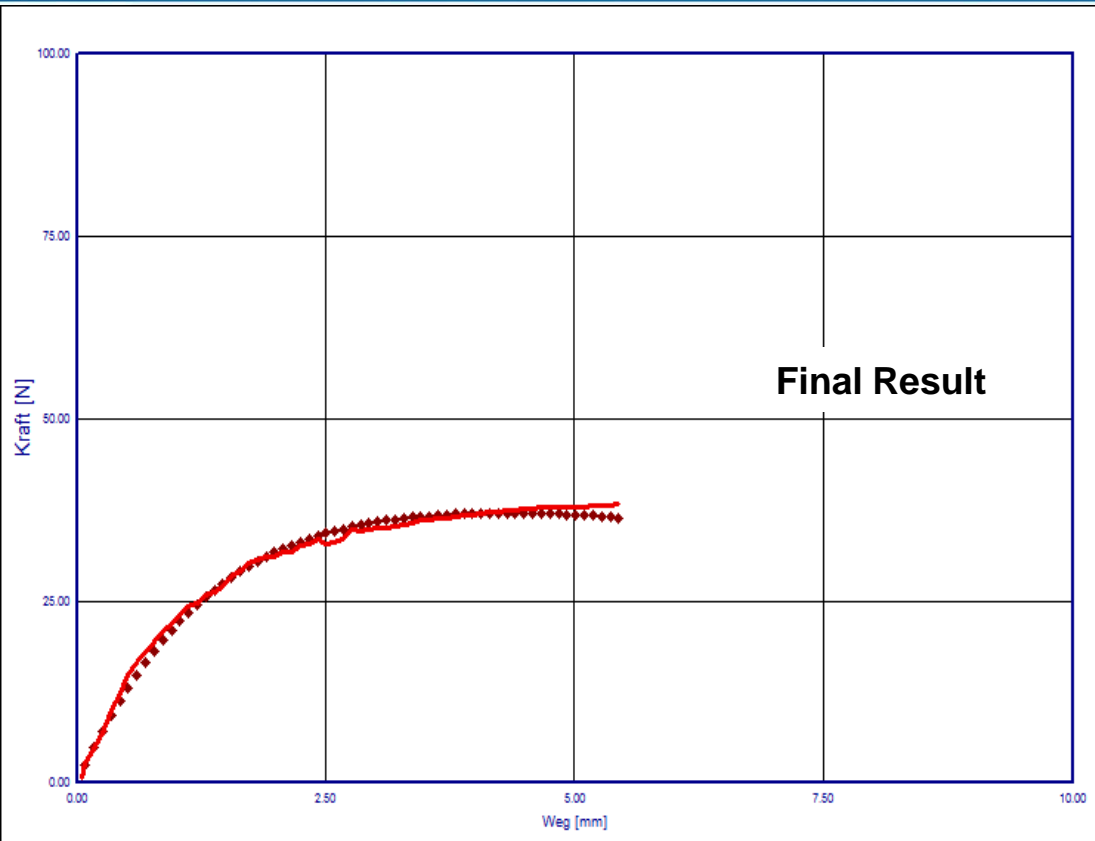


Materialcards



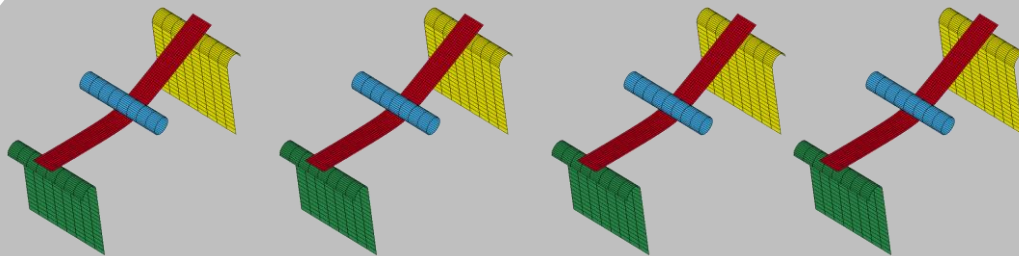






# Dynamische Materialcharakterisierung

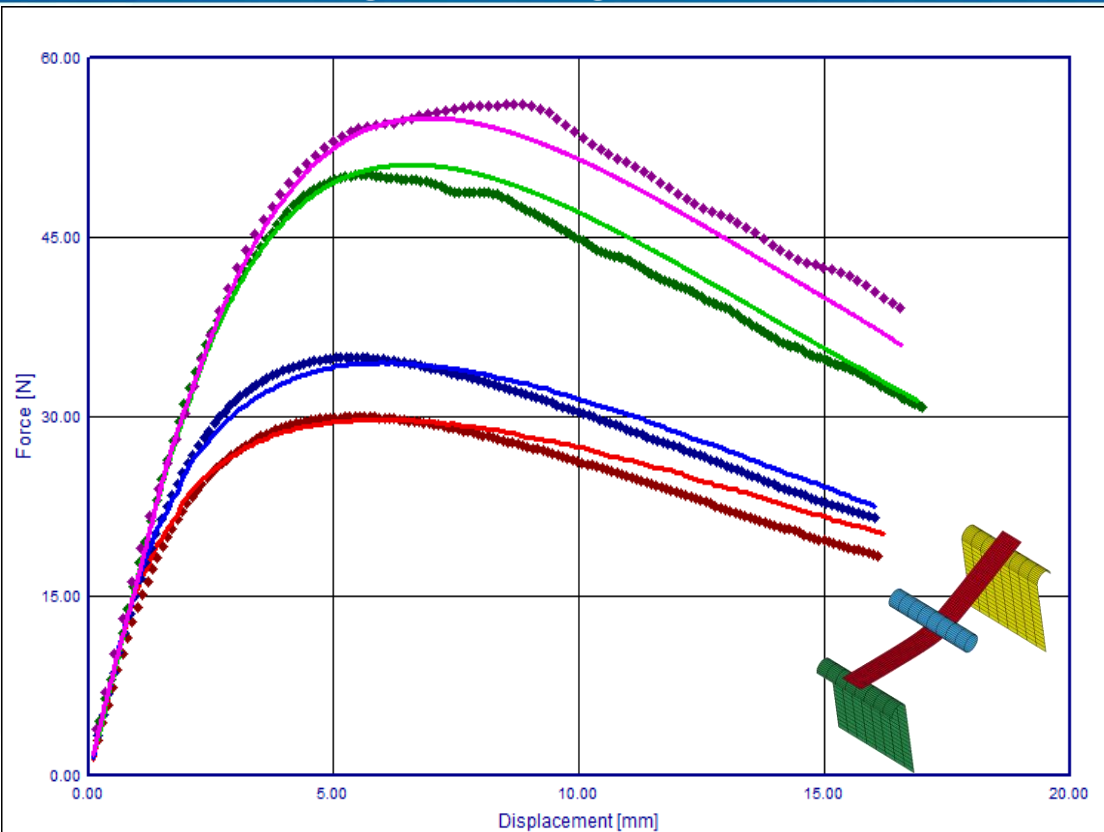
## Charakterisierungs-Pyramide



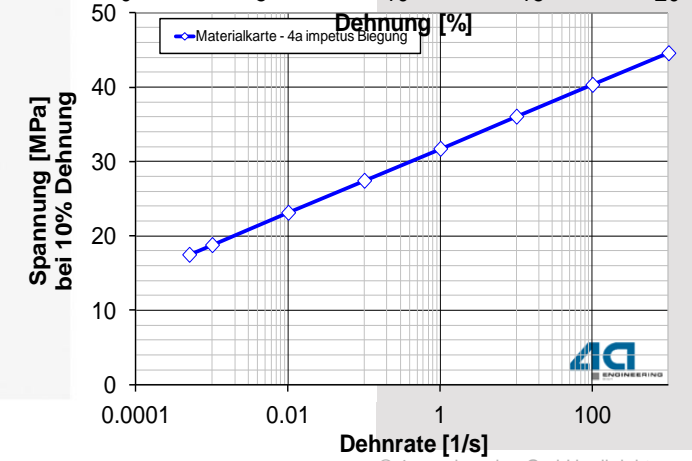
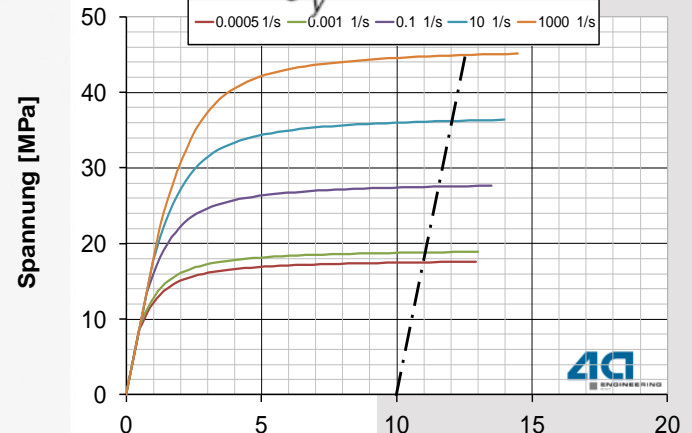
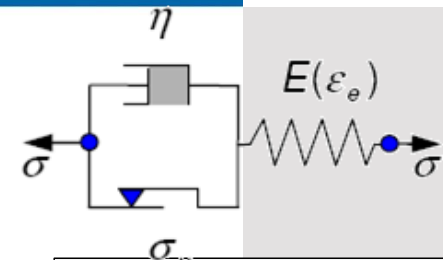
Elastizität,  
Plastizität, Dehnrage

# Dynamische Materialcharakterisierung

## Reverse Engineering - Dehnratenabhängigkeit



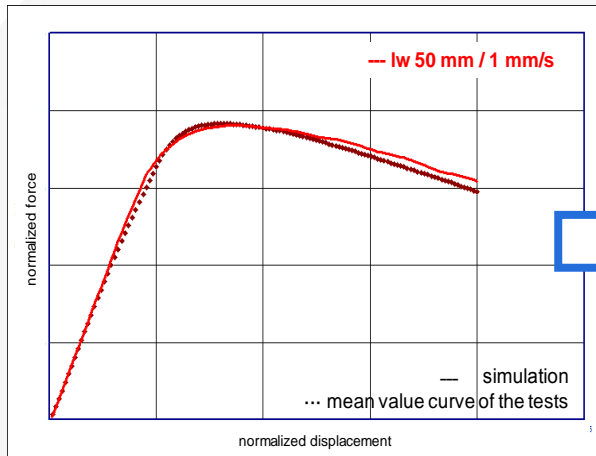
Geschw. [mm/s]	Auflagerabstand [mm]	Dehnrade [1/s]
0.1	40	0.002
1	40	0.02
1000	40	11
3000	40	80



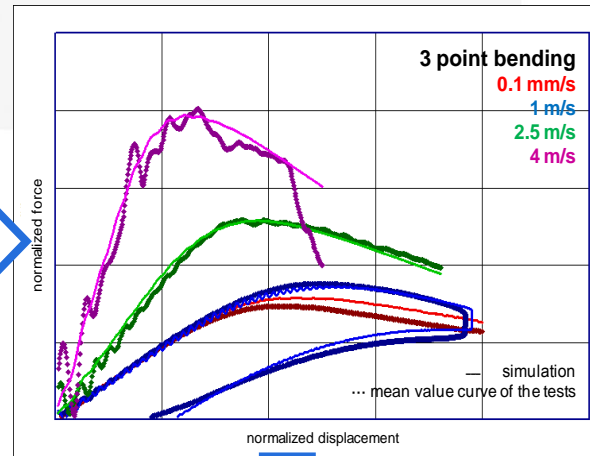
Quelle: [Reithofer TT2014](#)

# Dynamische Materialcharakterisierung

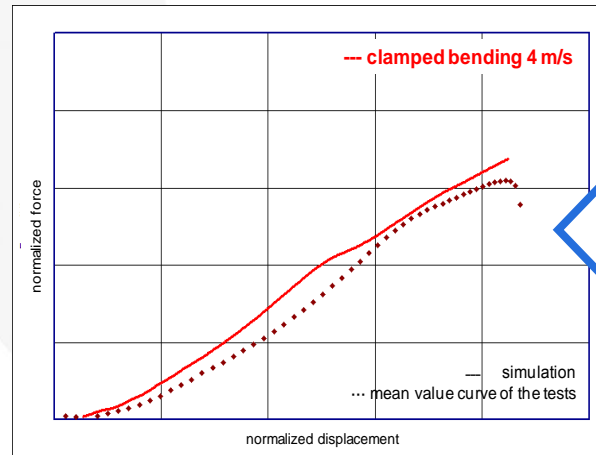
## Reverse Engineering - Workflow



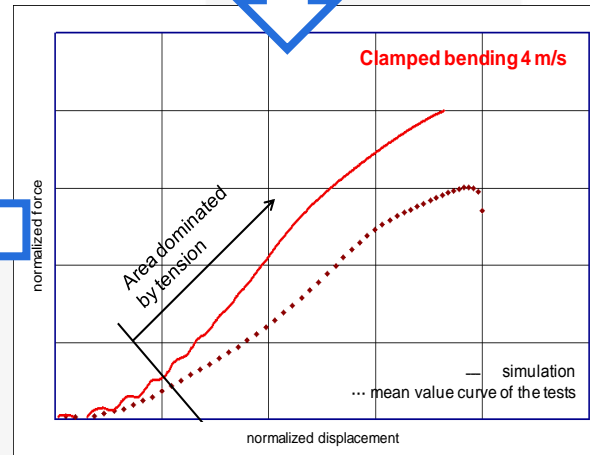
static behavior - yield



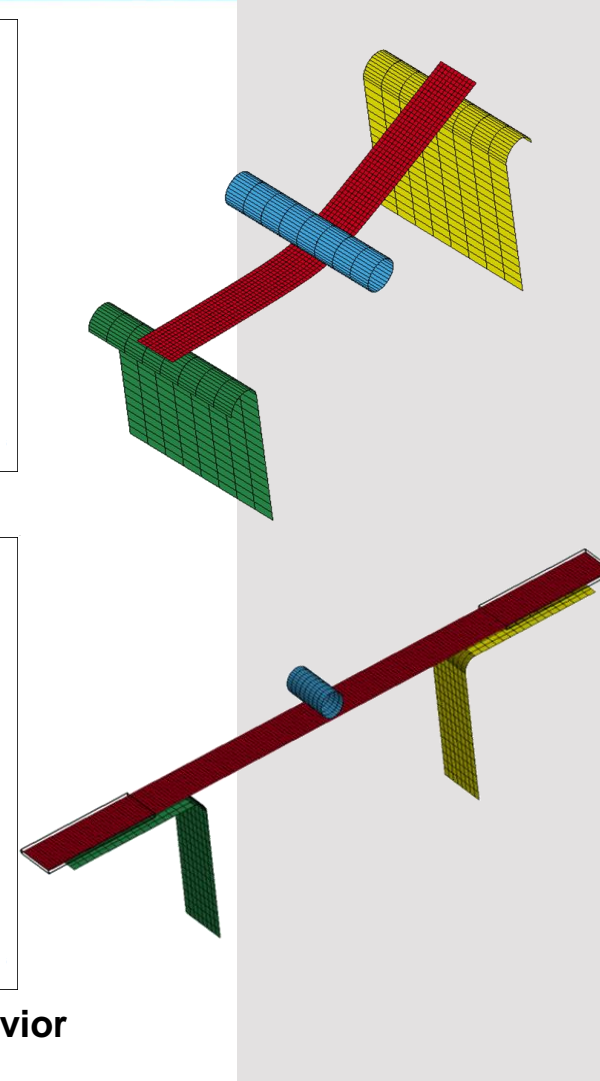
dynamic behavior - strain rate



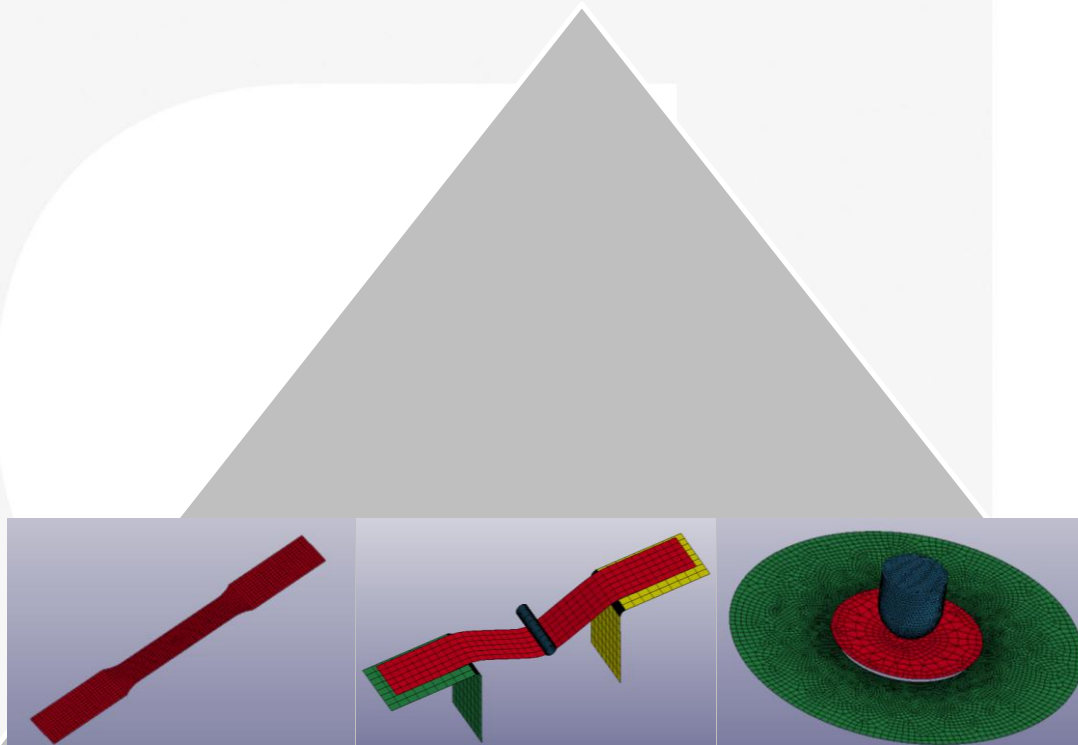
fit compression/tension behavior



check compression/tension behavior

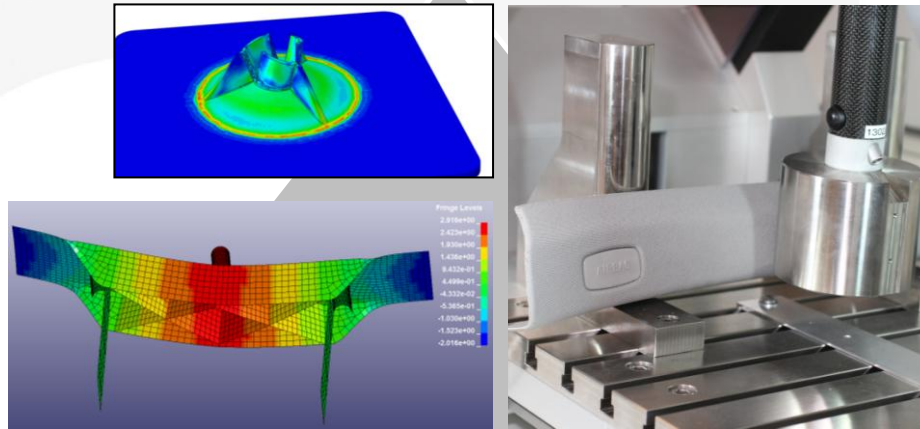


Quelle: [Fertschej et al., LS-DYNA Konferenz 2015, Würzburg](#)

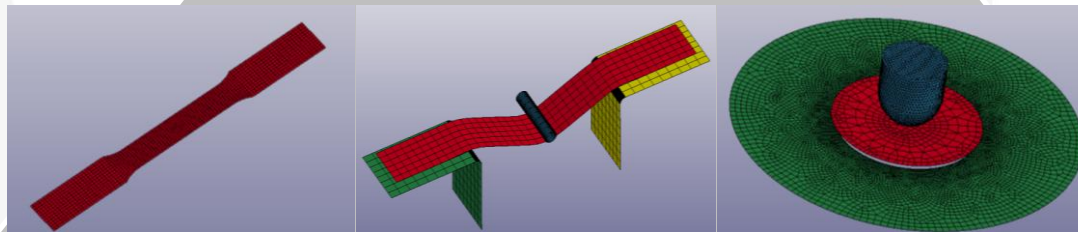


Mehrachsigkeit /  
Versagen

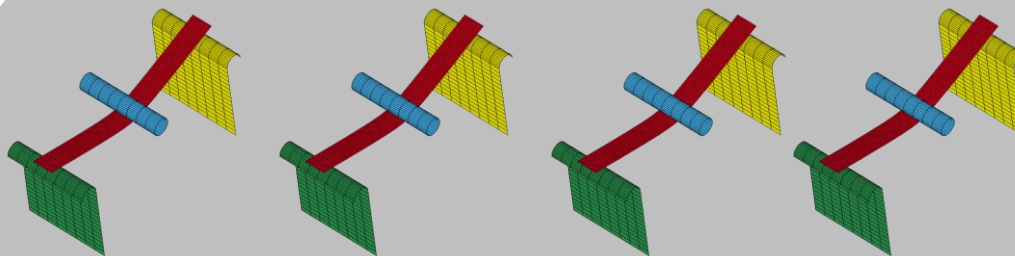
Elastizität, Plastizität,  
Dehnrage



Validierung

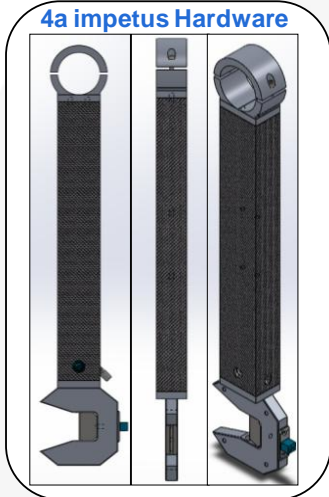


Mehrachsigkeit /  
Versagen



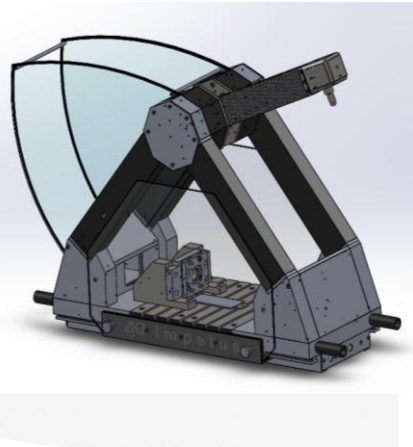
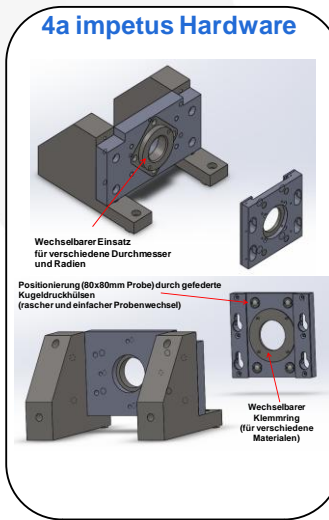
Elastizität, Plastizität,  
Dehnrage





Spezifikationen	
Pendellarmlänge	500 mm
mögliche Prüfgeschwindigkeiten	0,5-4,4 m/s
maximal zulässige Zusatzmassen	4000 g
maximal zulässige Prüfenergie	50J

**steifere Materialien  
Durchstoß  
Bauteilprüfung**



## Prozessautomatisierung

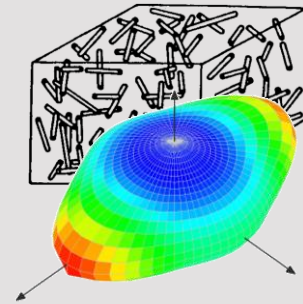
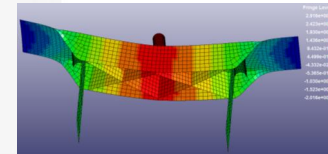
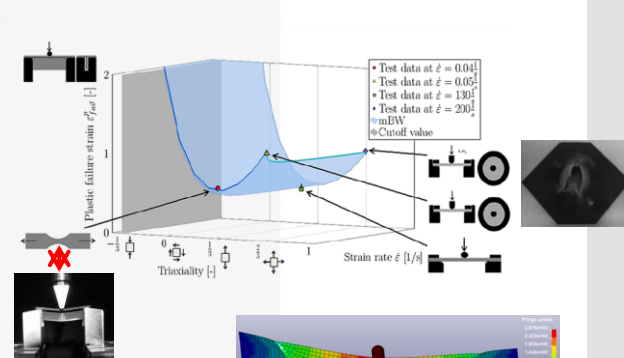
Automated\_Optimization

ID	Name	Optimization/Validation	Status	VP Autovalue
141204_003	Celstran - E-Modul	Validation	●	<input type="checkbox"/>
141204_005	Celstran - plast	Optimization	●	<input type="checkbox"/>
▶ 141204_006	Celstran - strain rate	Optimization	●	<input checked="" type="checkbox"/>
141204_007	Celstran - validation	Validation	●	<input type="checkbox"/>

calc max strain  
 calc strainrates

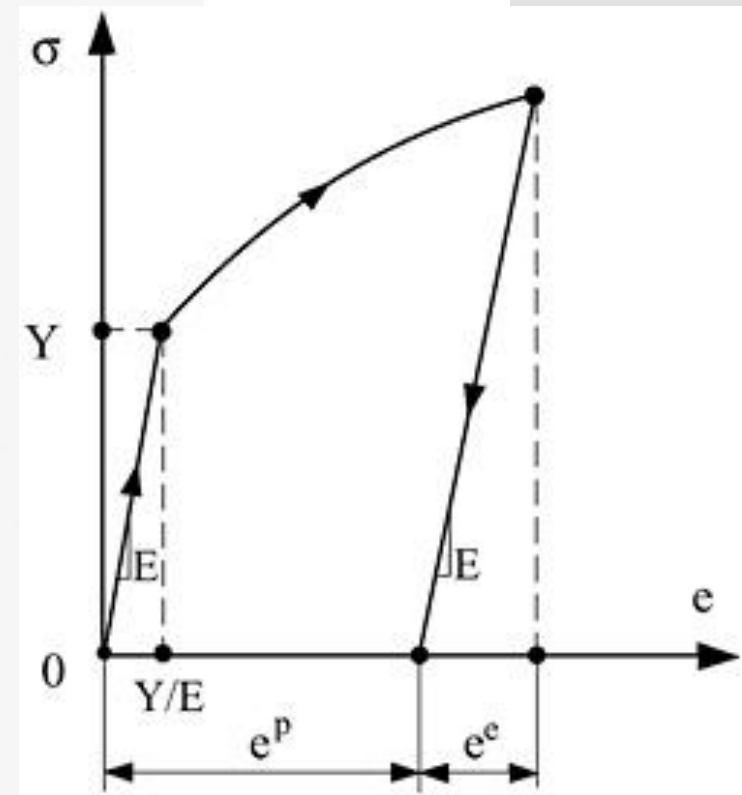
Calc auto values    Clear

DV	Autovalue	141204_003	141204_005	141204_006	141204_007
▶ e_E	6392.7	6359.221	PRUN(c)	PRUN(c)	PRUN(c)
s_ET	12.219	n.a.	1000	1000	1000
s_h	69.887	n.a.	AUTO	PRUN(c)	PRUN(c)
s_y	69.887	n.a.	AUTO	PRUN(c)	PRUN(c)
v_epspkt	0.001	n.a.	AUTO(c)	AUTO(c)	PRUN(c)
v_p	11.855	n.a.	AUTO(c)	AUTO	PRUN



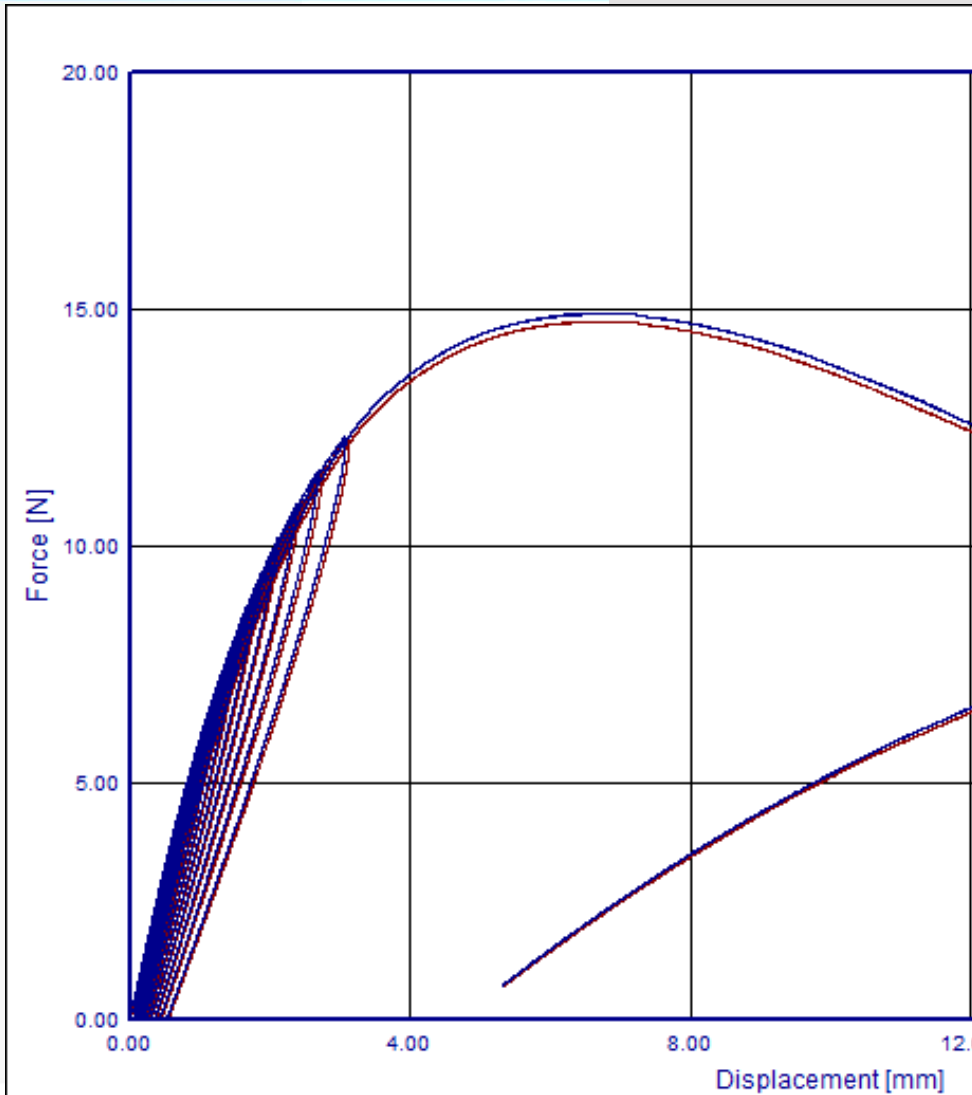
**Versagen  
Anisotropie  
Validierung**

- Spannungs-Dehnungskurven
  - Zug (oder Biegung)
  - Campus
- Materialmodelle
  - **Elastisch - Plastisch**
  - Anisotropie
- Einflüsse
  - Temperatur
  - Zeit
  - ...

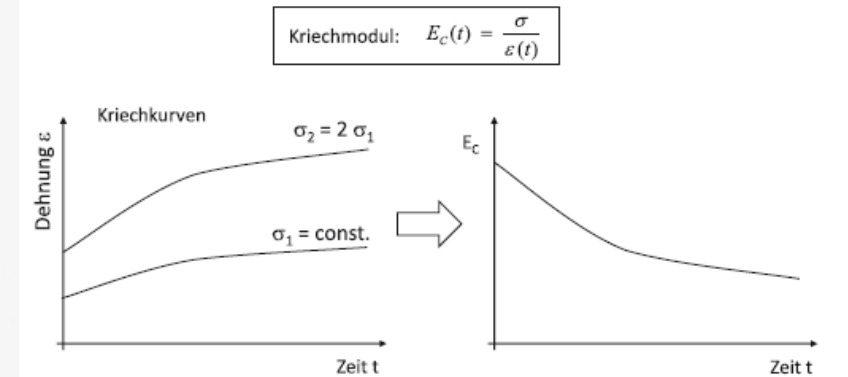


Quelle: <http://www.globalspec.com>

- Spannungs-Dehnungskurven
  - Zug (oder Biegung)
  - Campus
- Materialmodelle
  - **Elastisch - Plastisch**
  - Anisotropie
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  - ...

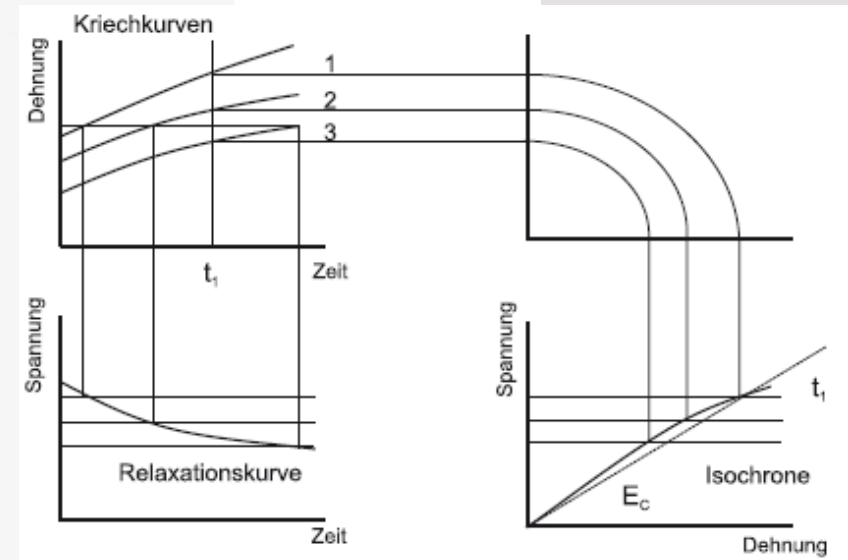


- Kriechkurven
  - Zug oder Biegung
  - Campus
- Quasistatische Ersatzmodelle
  - **Kriechmodul Zeit**
  - Isochrone Spannungs-Dehnungskurven ableiten
- Kriechmodelle
  - Norton Bailey
- Lineare Viskoelastizität
  - Prony Serie



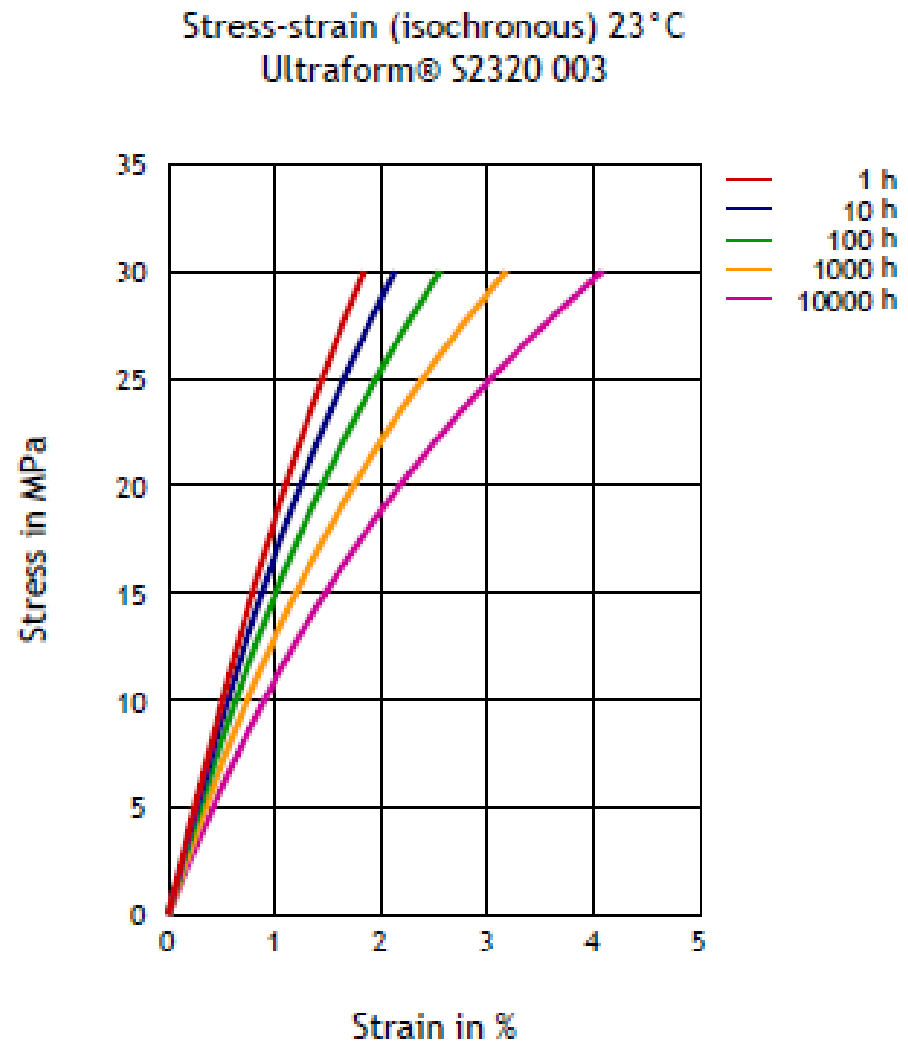
Quelle: FEM zur Berechnung von Kunststoff- und Elastomerbauteilen, M. Stommel (HANSER)

- Kriechkurven
  - Zug oder Biegung
  - Campus
- Quasistatische Ersatzmodelle
  - Kriechmodul Zeit
  - **Isochrone Spannungs-Dehnungskurven ableiten**
- Kriechmodelle
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  - Prony Serie



Quelle: FEM zur Berechnung von Kunststoff- und Elastomerbauteilen, M. Stommel (HANSER)

- Kriechkurven
  - Zug oder Biegung
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- Kriechmodelle
  - Norton Bailey
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  - Prony Serie



CAMPUS: Isochrone Spannungs-Dehnungskurve bei 23°C für Ultraform® S2320 003 – POM (BASF)

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- Kriechkurven
  - Zug oder Biegung
  - Campus
- Quasistatische Ersatzmodelle
  - Kriechmodul Zeit
  - Isochrone Spannungs-Dehnungskurven ableiten
- Kriechmodelle
  - **Norton Bailey**
- Lineare Viskoelastizität
  - Prony Serie

$$\bar{\varepsilon}^c = A \bar{\sigma}^n \bar{t}^m$$

$$\bar{\sigma} = \sqrt{\frac{3}{2} \sigma_{ij} \sigma_{ij}}$$

$\bar{\varepsilon}^c$  ... Effektive Kriechdehnungen

$A$  ... Spannungskoeffizient

$n$  ... Spannungsexponent

$m$  ... Zeitexponent

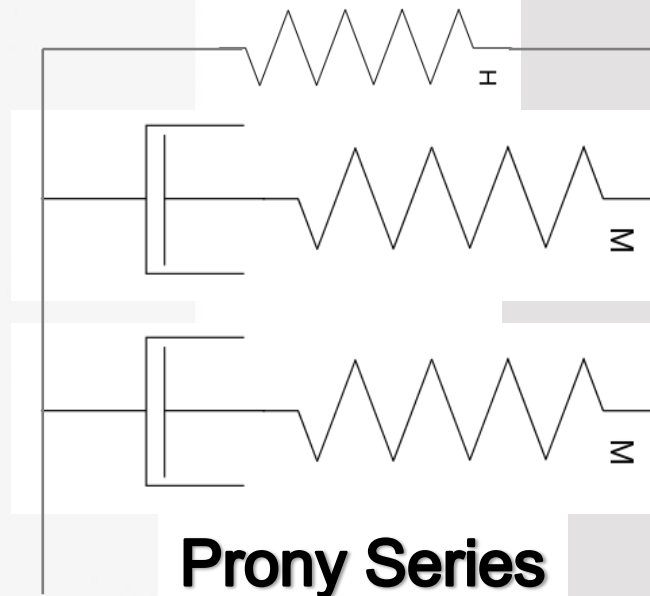
$\bar{\sigma}$  ... Effektive Spannungen

$\bar{t}$  ... Effektive Zeit

Quelle: [Wimmer, TT 2012](#)

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- Kriechkurven
  - Zug oder Biegung
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- Quasistatische Ersatzmodelle
  - Kriechmodul Zeit
  - Isochrone Spannungs-Dehnungskurven ableiten
- Kriechmodelle
  - Norton Bailey
- Lineare Viskoelastizität
  - **Prony Serie**





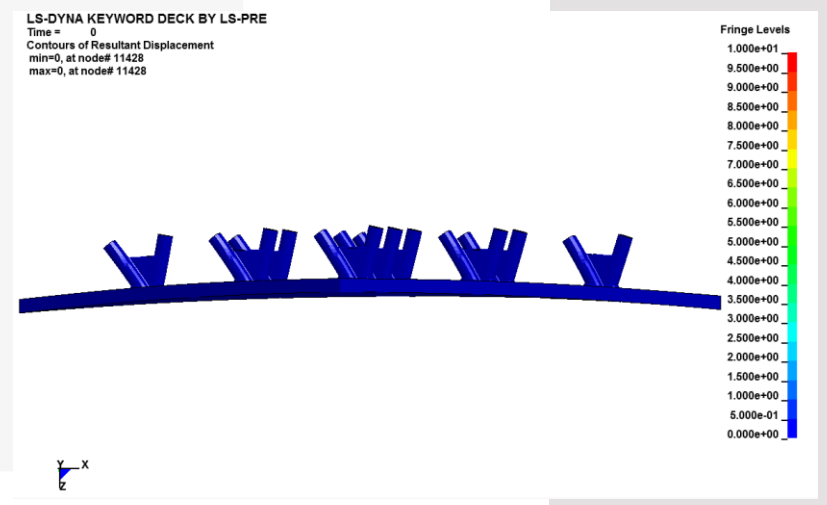
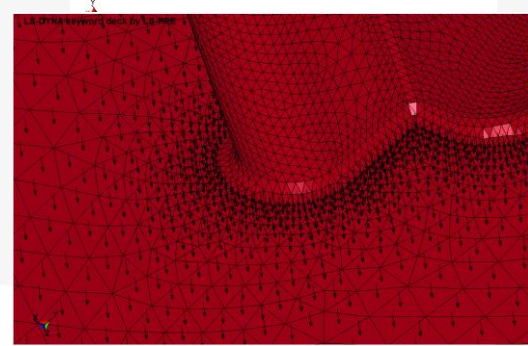
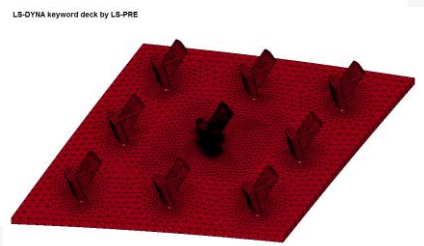
### Liner für Betonrohre



### Komponentenversuch Betonenschutzplatte 1270h bei 1,5 bar



Quelle: [Wimmer, TT 2012](#)



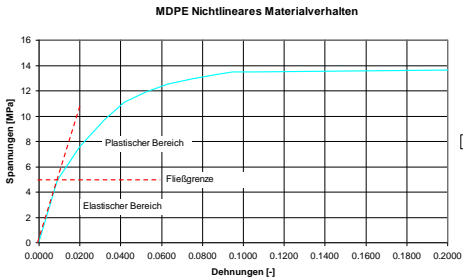
# Langzeitverhalten – Kriechen

## Anwendungsbeispiele HDPE (Agru GmbH)

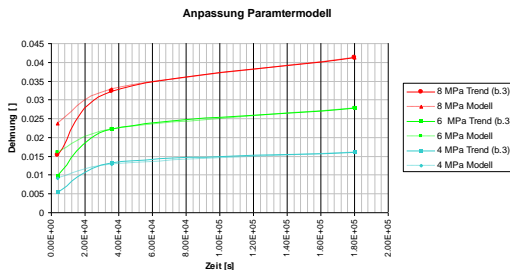
### Linear Elastisch

Kurzzeitbelastung bei 30°C  
 $E=550 \text{ MPa}$   
 $\eta=0.38$

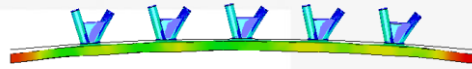
### Elastisch-Plastisch



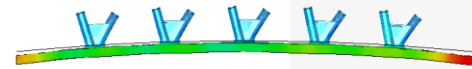
### Viskoelastisch



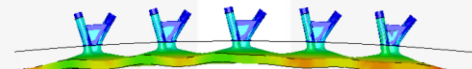
LS-DYNA KEYWORD DECK BY LS-PRE  
 Time = 1  
 Contours of Resultant Displacement  
 min=0, at node# 171418  
 max=2.56526, at node# 1



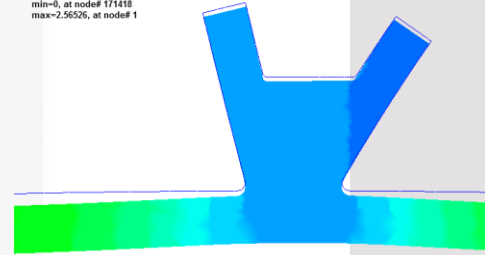
LS-DYNA KEYWORD DECK BY LS-PRE  
 Time = 1  
 Contours of Resultant Displacement  
 min=0.324754, at node# 11841  
 max=2.61022, at node# 1



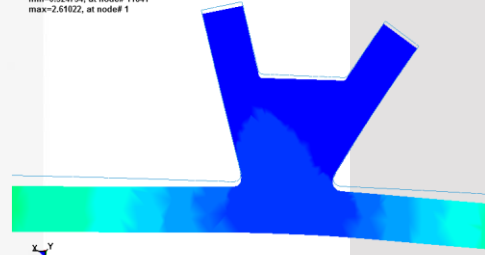
LS-DYNA KEYWORD DECK BY LS-PRE  
 Time = 1.577e+009  
 Contours of Resultant Displacement  
 min=0, at node# 171418  
 max=12.1729, at node# 1



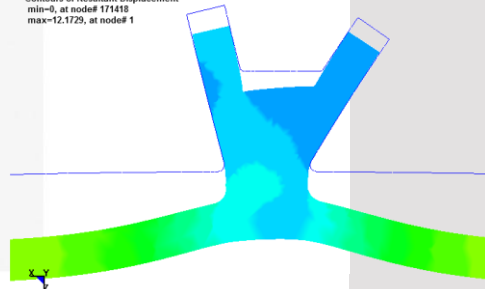
LS-DYNA KEYWORD DECK BY LS-PRE  
 Time = 1  
 Contours of Resultant Displacement  
 min=0, at node# 171418  
 max=2.56526, at node# 1



LS-DYNA KEYWORD DECK BY LS-PRE  
 Time = 1  
 Contours of Resultant Displacement  
 min=0.324754, at node# 11841  
 max=2.61022, at node# 1



LS-DYNA KEYWORD DECK BY LS-PRE  
 Time = 1.577e+009  
 Contours of Resultant Displacement  
 min=0, at node# 171418  
 max=12.1729, at node# 1



Quelle: [Wimmer, TT 2012](#)

- Beispiel
  - Beladen von Auto (Last auf Stoßstange)
  - Temperaturwechsel (100h 80°C, 60°C, -20°)
- Materialmodelle
  - Elastisch - Plastisch
  - Creep Law
- Prüfungen (Zug)
  - Statisch (Temperatur)
  - Kriechen



Quelle: <http://www.rad-ab.com/tag/opel-astra/>

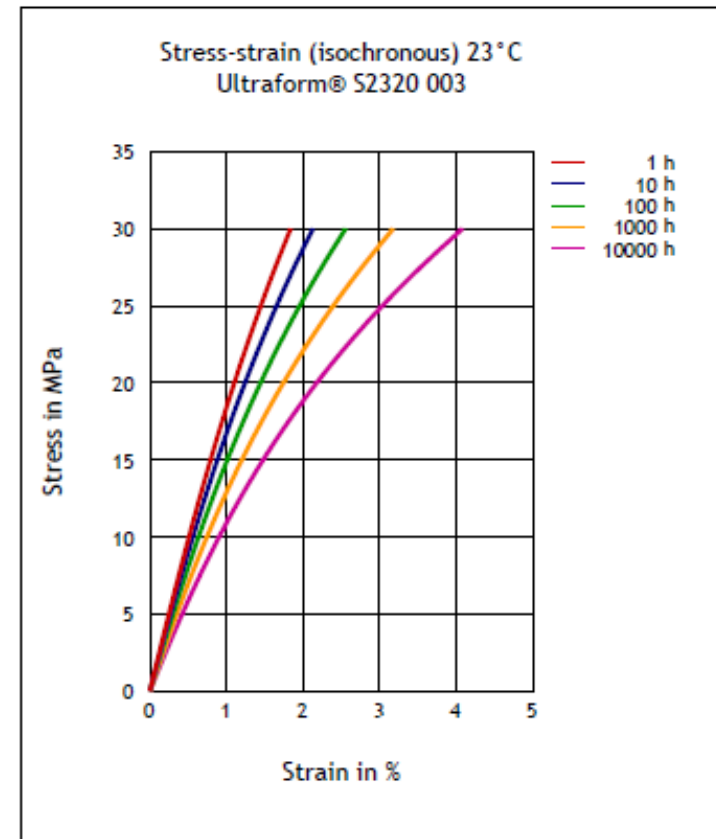
**Entlastung ?**  
**→ Prony Series**

**Alternativen**

- **Biegung**
- **Mittlere Prüfzeit**

- Ersatzprüfprogramm
  - Biegung
  - Zug
- Materialmodelle
  - Creep Law
  - Reverse Engineering
- Vergleich
  - Isochrone Spannungs-Dehnungsdiagramme

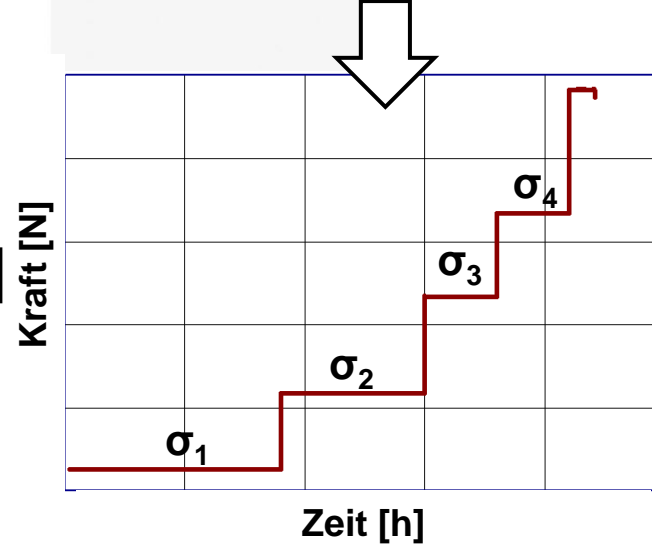
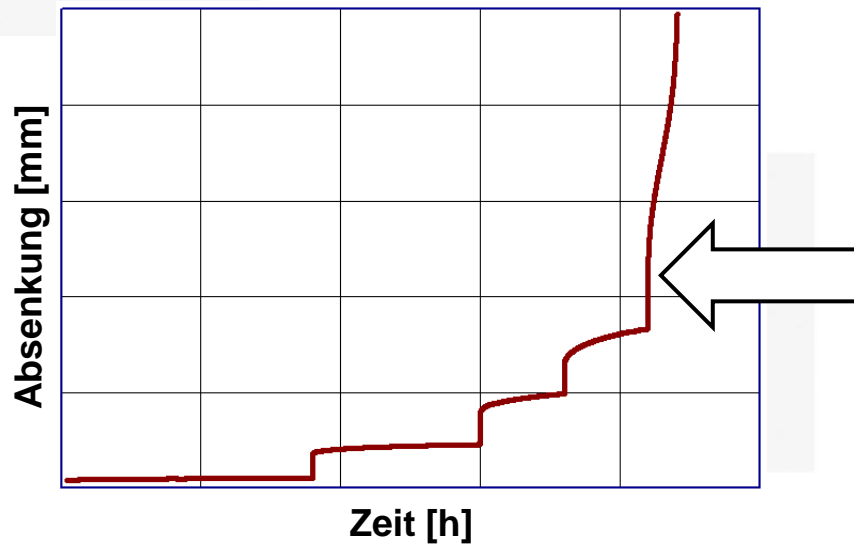
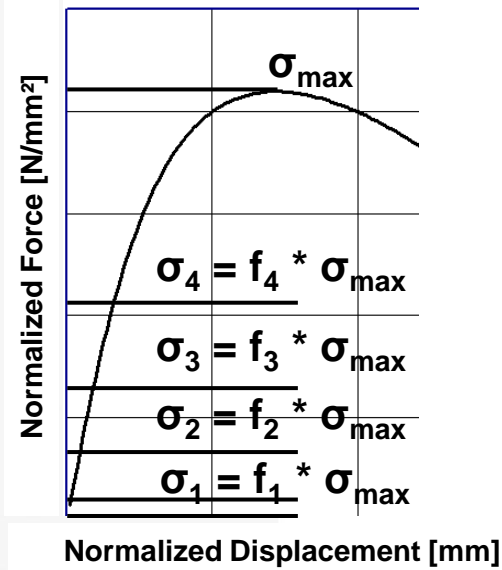
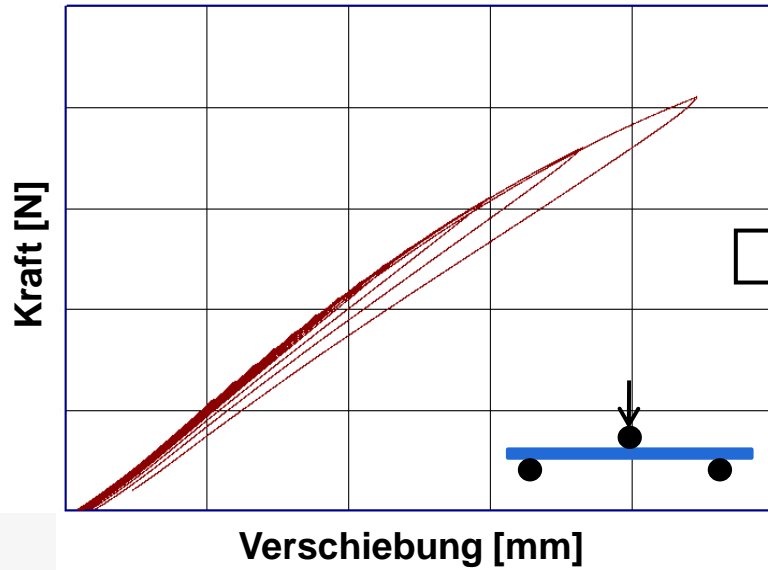
Stress-strain (isochronous) 23 °C

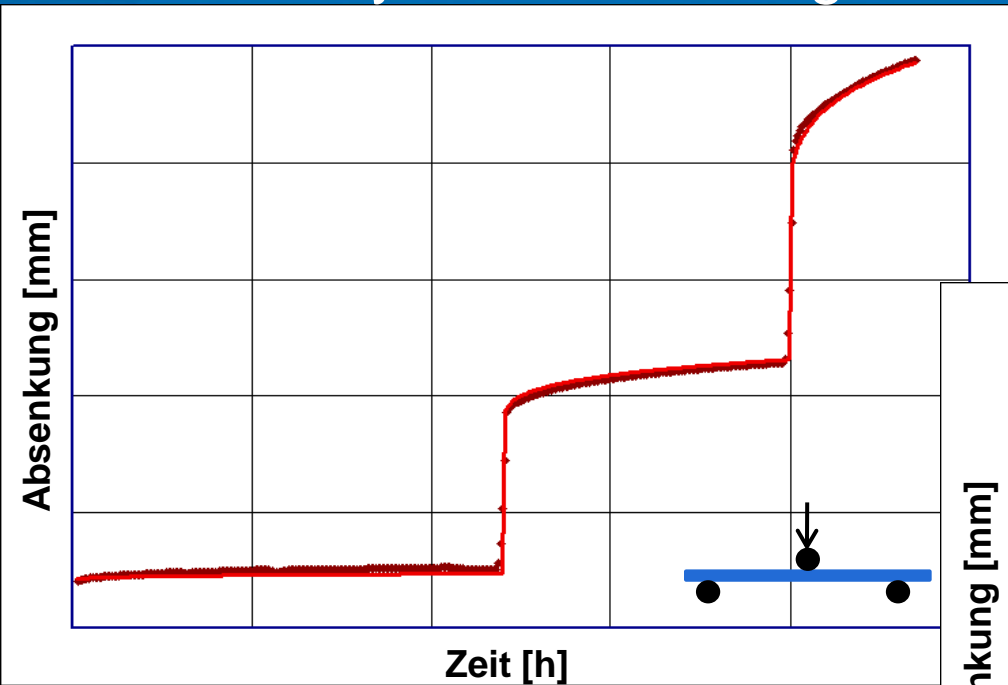


CAMPUS: Isochrone Spannungs-Dehnungskurve bei 23°C für Ultraform® S2320 003 – POM (BASF)

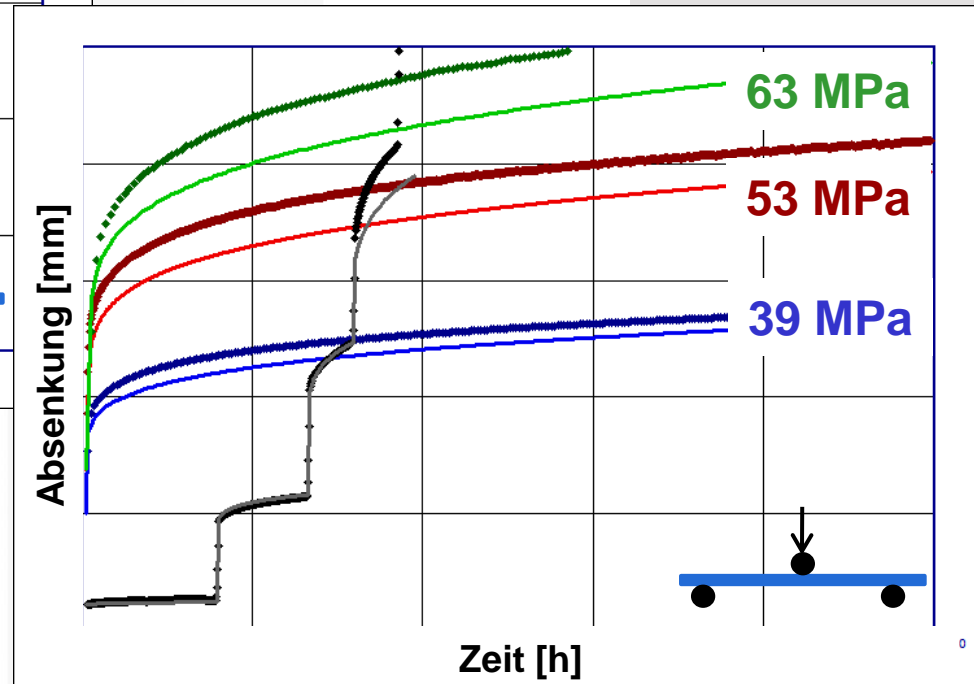
# Zeitabhängiges Materialverhalten

## alternative Vorgehensweise





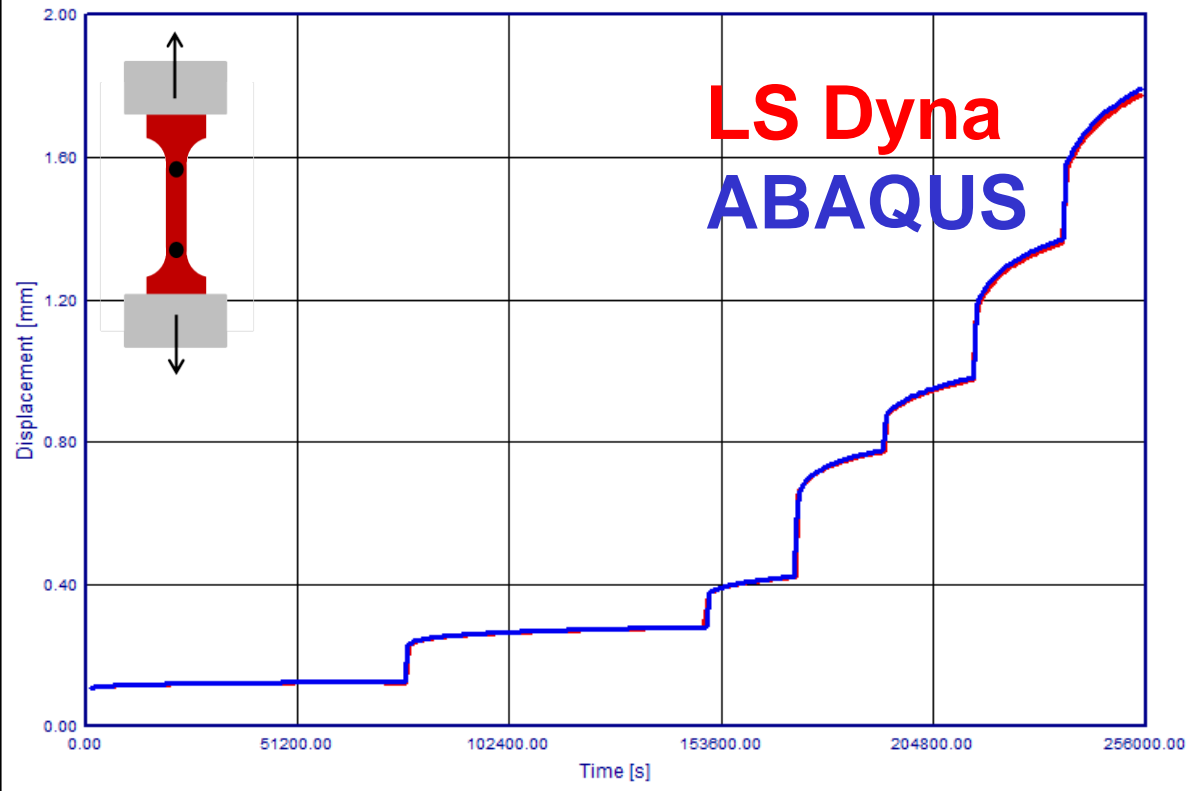
Optimierung auf  $\sigma_1$ - $\sigma_3$



Validierung  $\sigma_1$ - $\sigma_5$   
& andere Versuche

# Zeitabhängiges Materialverhalten

## Norton Bailey – Vergleich Solver



$$\bar{\epsilon}^c = A \bar{\sigma}^n \bar{t}^m$$

$\bar{\epsilon}^c$  ... Effektive Kriechdehnungen

$A$  ... Spannungskoeffizient

$n$  ... Spannungsexponent

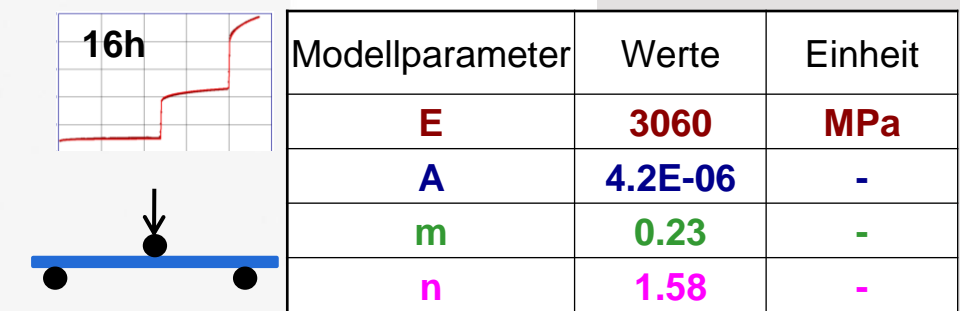
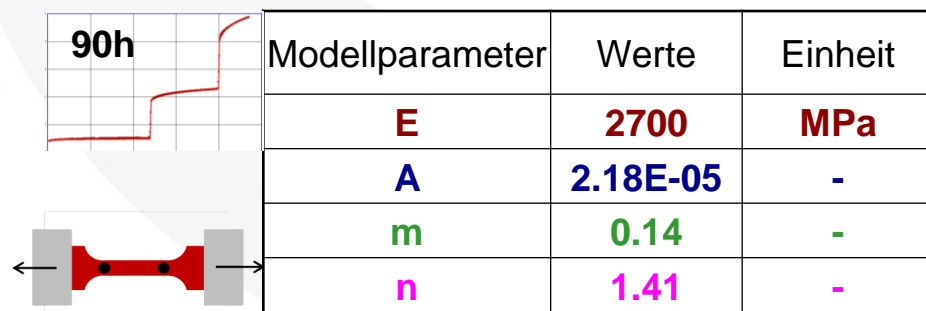
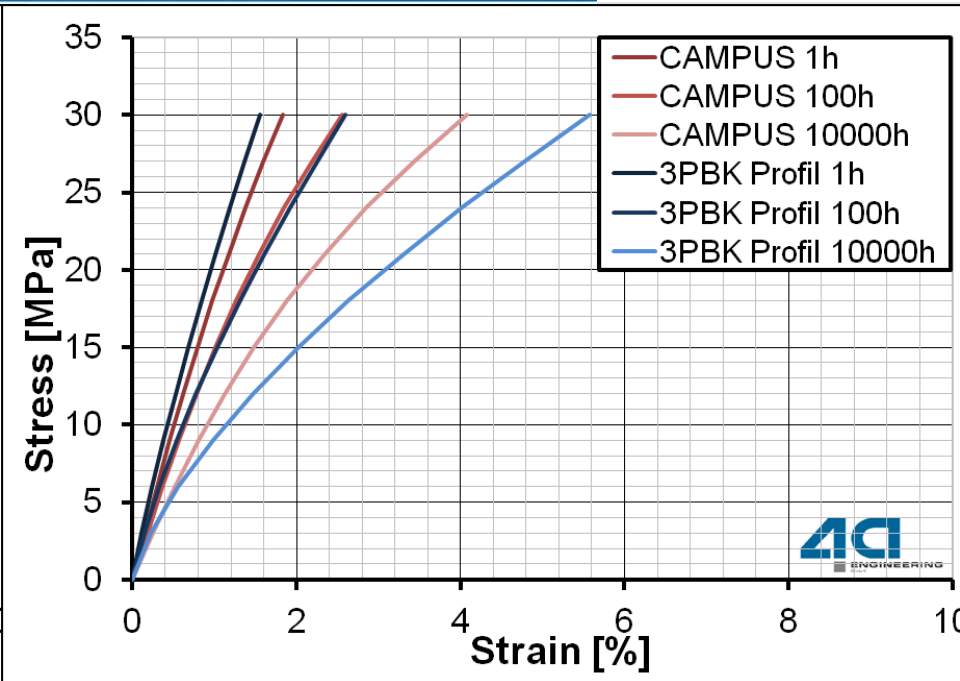
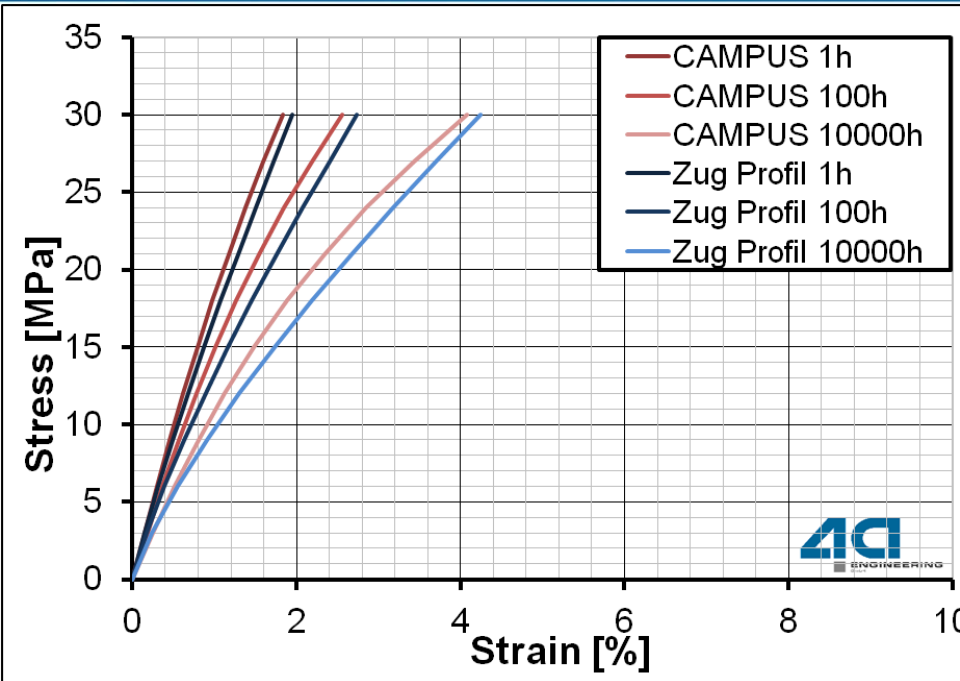
$m$  ... Zeitexponent

$\bar{\sigma}$  ... Effektive Spannungen

$\bar{t}$  ... Effektive Zeit

# Zeitabhängiges Materialverhalten

## Vergleich





- dynamisches Verhalten von Kunststoffen und Schäumen
  - Realitätsnah auf's wesentliche reduziert (Biegung /Druck)
  - Standard – LSDYNA, ABAQUS, PamCrash
  - Schnell und kostengünstig verfügbar
- neue Themen - Kurzzeitverhalten
  - **Versagen von Kunststoffen**
  - Kleinkomponenten Validierung
  - **Anisotropie → Standardmaterialkarten** in LSDYNA und ABAQUS
- neue Themen - Allgemein
  - **Bleibende Verformung** / Kriechen / **Temperaturwechseltest**
  - **Reibung** / Tribologie
- neue Themen - Kurzzeitverhalten
  - geschäumte Kunststoffe (MuCell, chemisches Schäumen, ...)
  - **Aluminium / Metalle**

