Integrative Simulation von kurz- und langglasfaserverstärkten Kunststoffen

P. Reithofer
4a engineering GmbH, Traboch, Austria

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Inhalt

- Wie verhalten sich SFRT/LFRT Kunststoffe
- Welche Simulationstools gibt es
- Wie sieht eine Simulationsprozesskette aus
- Welche Informationen sind wann verfügbar
- Welche Softwaretools bietet 4a

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Einleitung
Unterteilung polymere Verbundwerkstoffe

- Matrix
  - **Thermoplast**
  - Duroplast
- Partikel oder Faser (Verstärkung)
  - Talkum (Plättchen)
  - Glaskugeln
  - **Glasfaser (isotrop)**
  - Aramid, Carbon (transversal isotrop)
  - Naturfasern, Holz, Stahl, …

⇨ **elastisch/plastisch**
Belastungsart
Zeit / Temperatur

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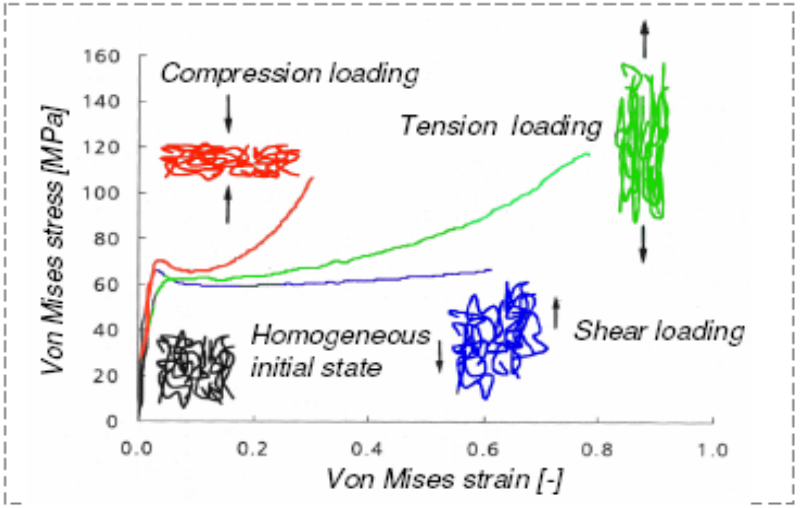
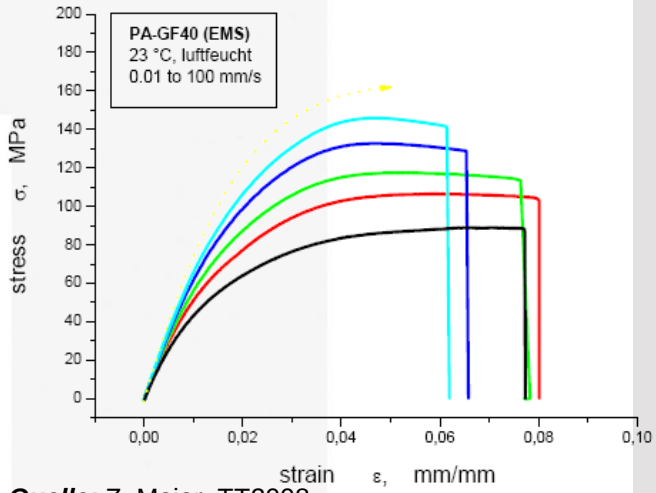
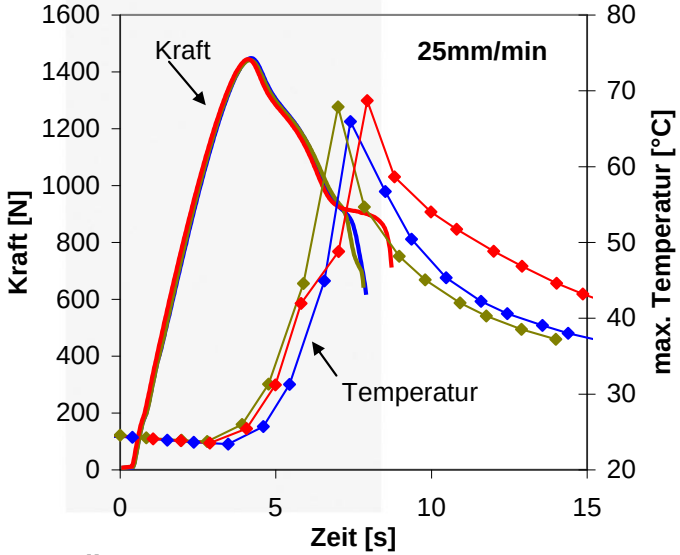
Einleitung
Matrixverhalten



Quelle: Mechanik der Kunststoffe, *W. Retting, Hanser Verlag 1991*



Quelle: Z. Major, TT2008



Quelle: J. Strauch, TT2012

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Einleitung
Unterteilung polymere Verbundwerkstoffe

- Matrix
  - **Thermoplast**
  - Duroplast
- Partikel oder Faser (Verstärkung)
  - Talkum (Plättchen)
  - Glaskugeln
  - **Glasfaser (isotrop)** ⇨ **Elastisch Anisotropie**
  - Aramid, Carbon (transversal isotrop)
  - Naturfasern, Holz, Stahl, …

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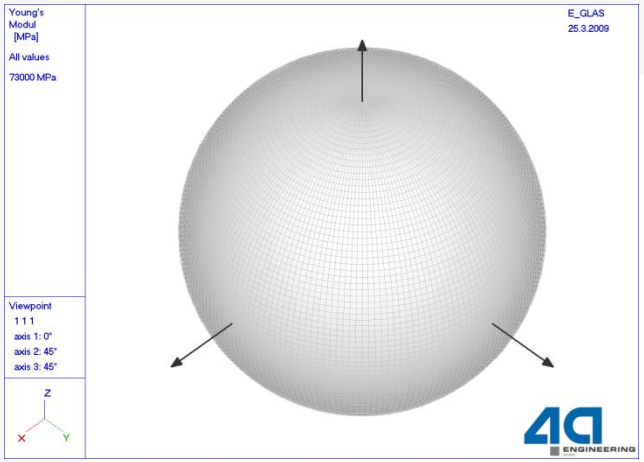
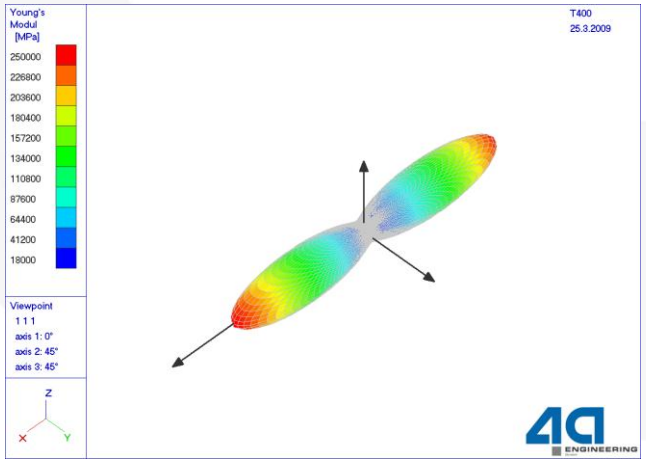
Anisotropie
Sonderformen der Anisotropie

Glasfaser (isotrop)



$$C^{-1} = \begin{bmatrix} \frac{1}{E} & -\frac{\nu}{E} & -\frac{\nu}{E} & 0 & 0 & 0 \\ -\frac{\nu}{E} & \frac{1}{E} & -\frac{\nu}{E} & 0 & 0 & 0 \\ -\frac{\nu}{E} & -\frac{\nu}{E} & \frac{1}{E} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{2(1+\nu)}{E} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{2(1+\nu)}{E} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{2(1+\nu)}{E} \end{bmatrix}$$

T400 (transversal isotrop)



$$C^{-1} = \begin{bmatrix} \frac{1}{E_1} & -\frac{\nu_{12}}{E_2} & -\frac{\nu_{13}}{E_2} & 0 & 0 & 0 \\ -\frac{\nu_{21}}{E_1} & \frac{1}{E_2} & -\frac{\nu_{23}}{E_2} & 0 & 0 & 0 \\ -\frac{\nu_{31}}{E_1} & -\frac{\nu_{32}}{E_2} & \frac{1}{E_2} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{2(1+\nu_{23})}{E_2} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{31}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{21}} \end{bmatrix}$$

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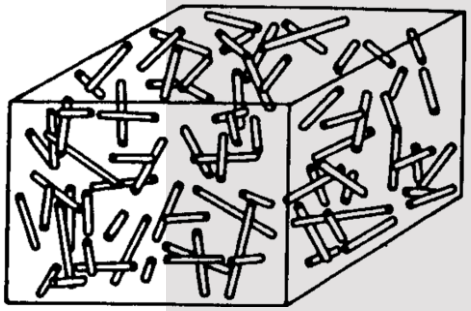
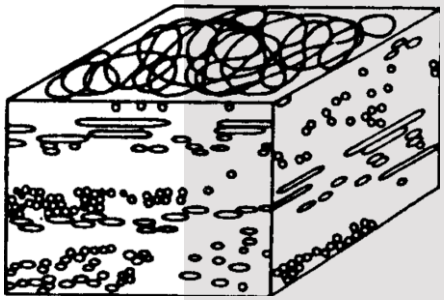
Einleitung
Unterteilung polymere Verbundwerkstoffe

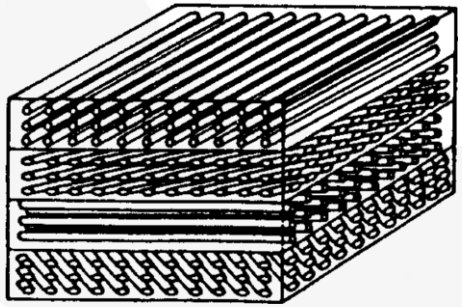
- unverstärkt
- Teilchen- oder partikelverstärkt (l/d<1)
- Kurzfaserverstärkt **(l/d 20-40, d~10µm)**
- Langfaserverstärkt **(l/d 100-200, d~20µm)**
- Endlosfaserverstärkt (l/d >> 1000)



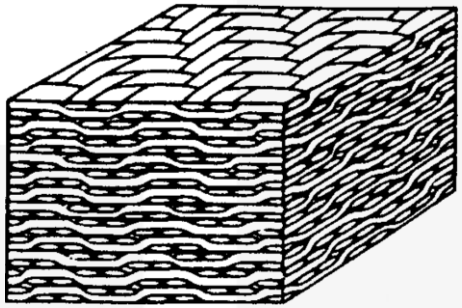
Kurz- bzw. Langfasern



Fasermatten



unidirektionale Faserschichten



Gewebe

Bildquelle: Physik und Werkstoffkunde der Kunststoffe VO02/03, Montanuniversität Leoben

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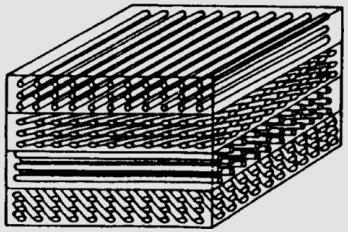
Anisotropie

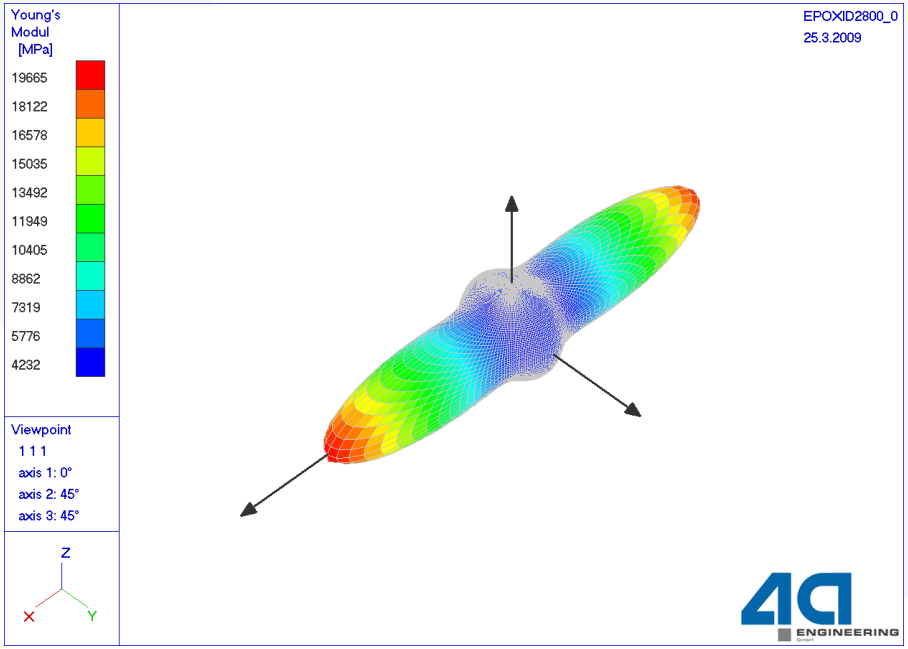
Mikromechanik – 3D Werkstoffdaten

Epoxid verstärkt mit 40% Glasfaser
(unidirektional verstärkt)

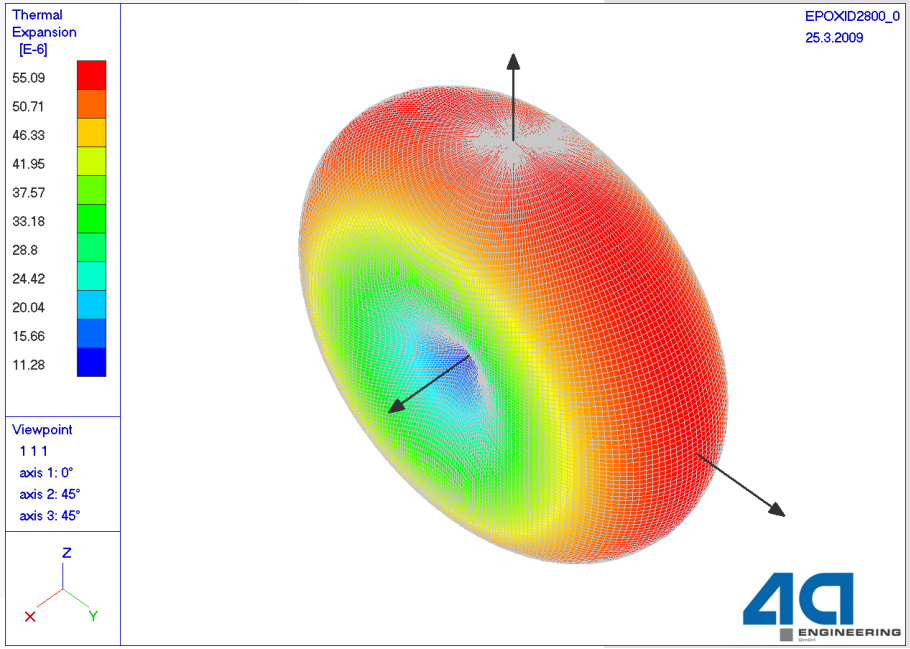


unidirektionale Faserschichten

E-Modul



thermische Ausdehnung



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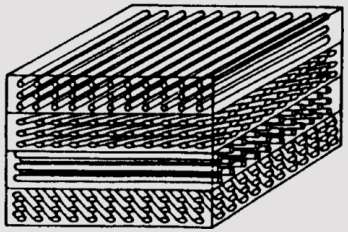
Anisotropie

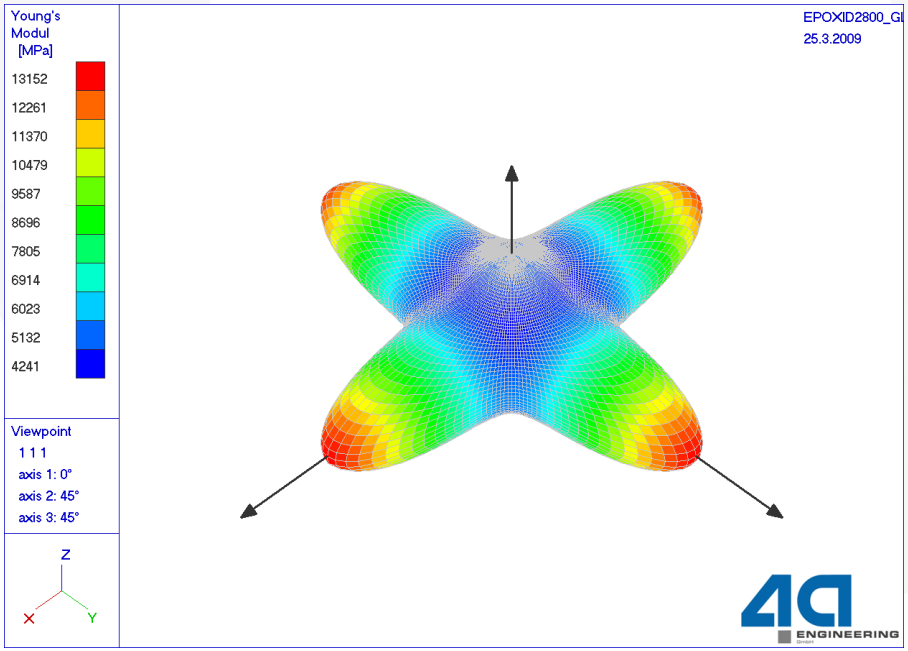
Mikromechanik – 3D Werkstoffdaten

Epoxid verstärkt mit 40% Glasfaser
(Laminat 0°/ 90°)

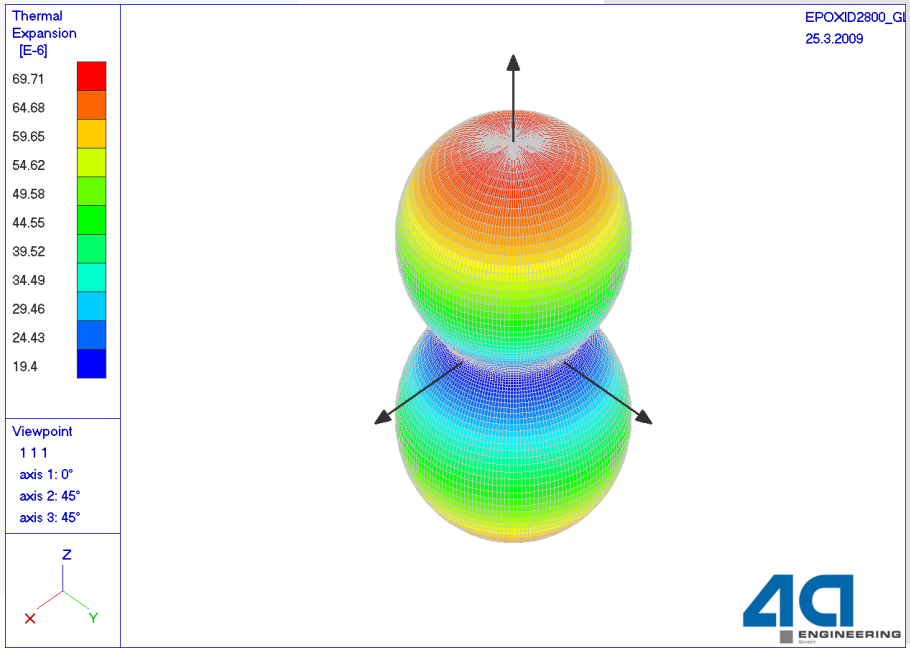


unidirektionale Faserschichten

E-Modul



thermische Ausdehnung



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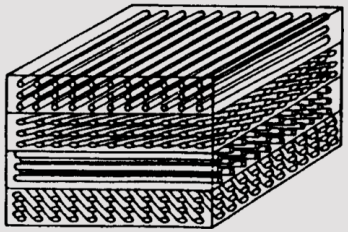
Anisotropie

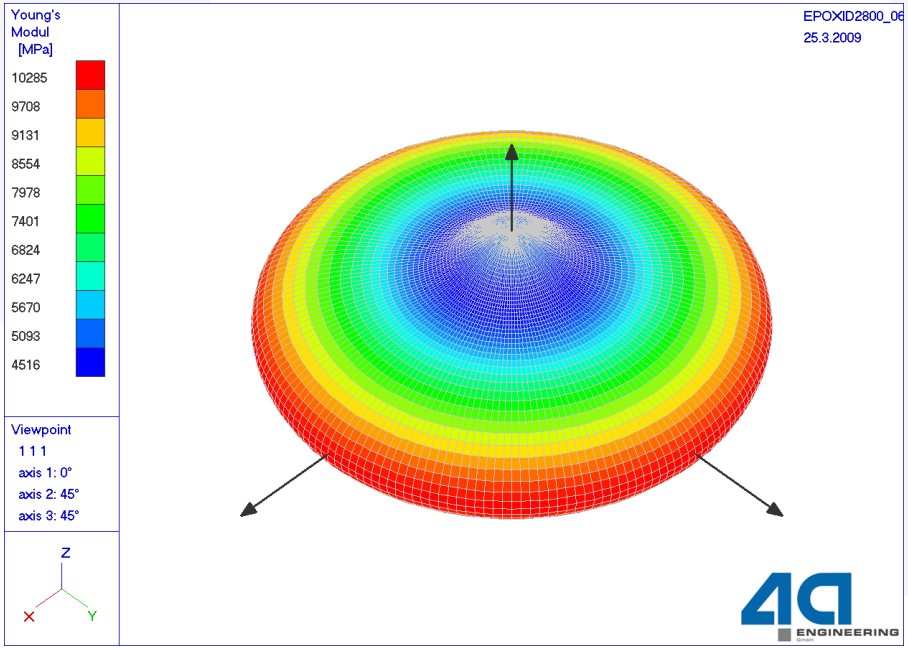
Mikromechanik – 3D Werkstoffdaten

Epoxid verstärkt mit 40% Glasfaser
(Laminat 0°/ 60° / -60 °)

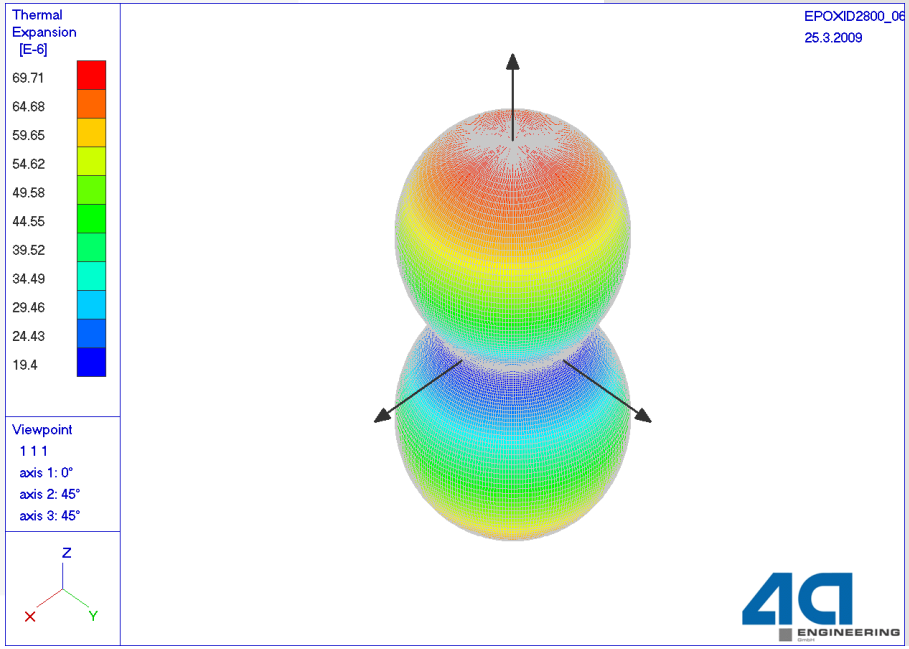


unidirektionale Faserschichten

E-Modul



thermische Ausdehnung



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Anisotropie

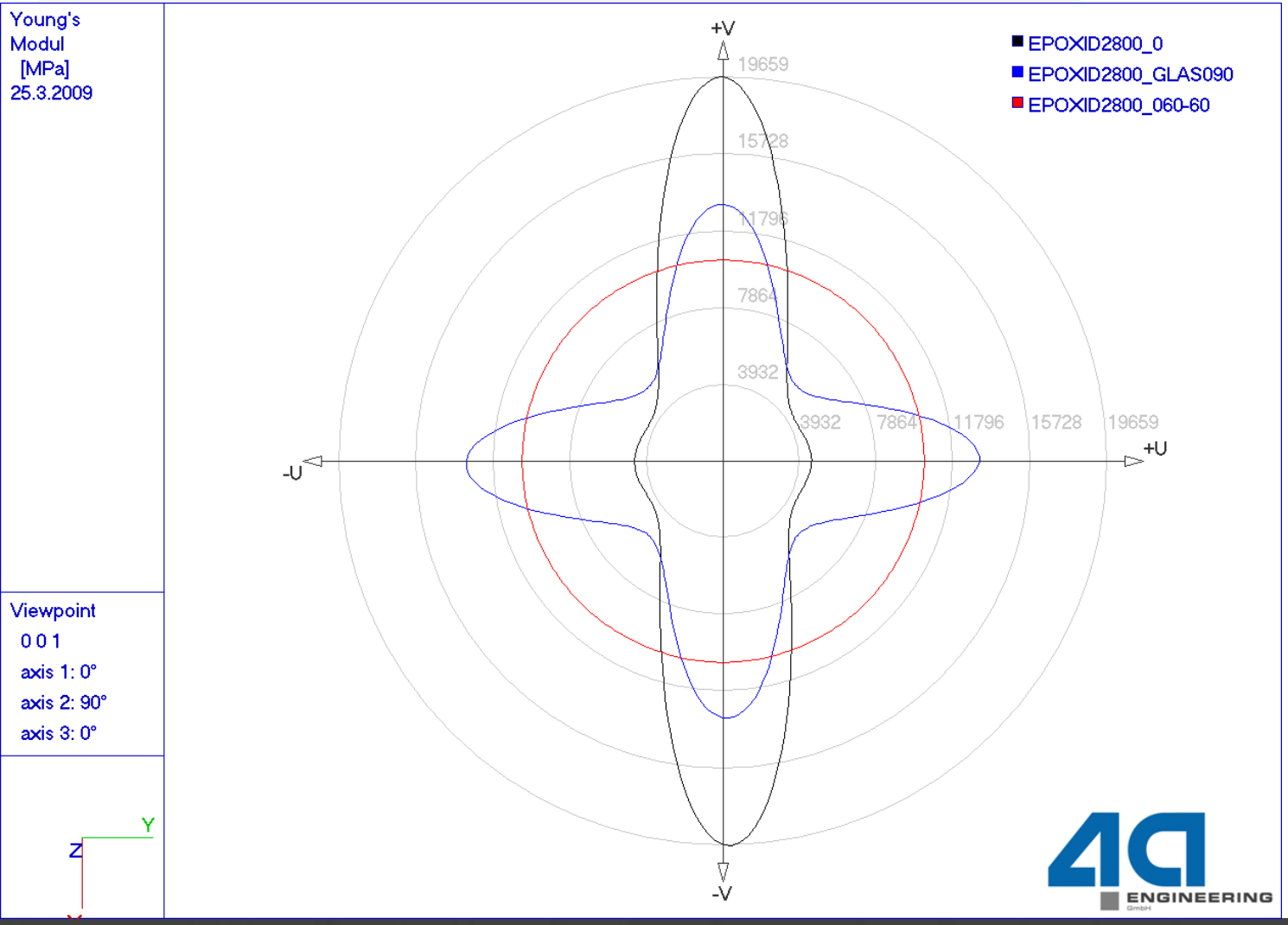
Mikromechanik – 3D Werkstoffdaten

Epoxid mit 40% Glasfaser verstärkt

unidirektional

0°/90°

-60°/0°/60°



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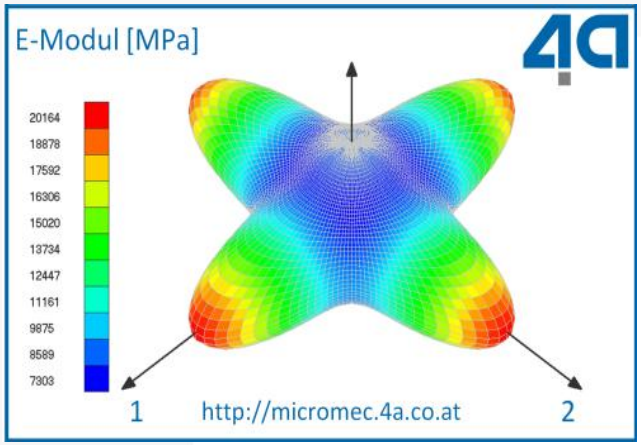
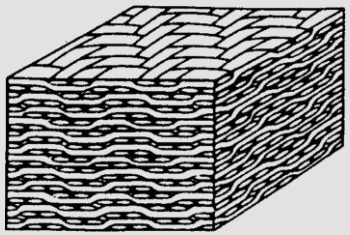
Anisotropie
Sonderformen

- Orthotropie (Gewebe) → 9 unabh. Unbekannte

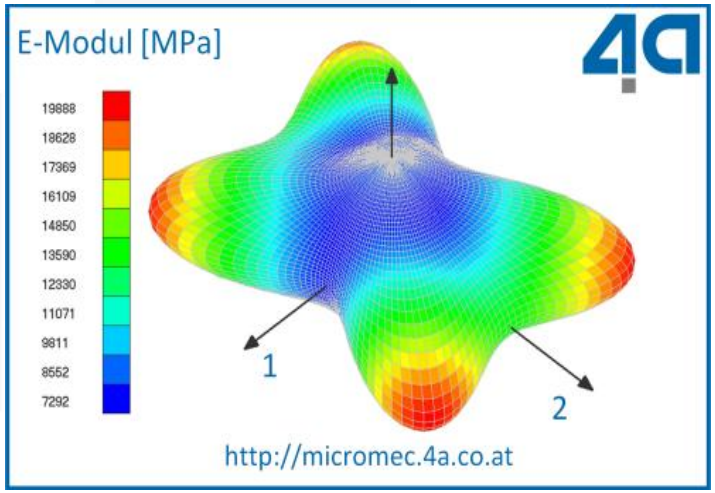


$$C^{-1} = \begin{bmatrix} \frac{1}{E_1} & -\frac{\nu_{21}}{E_2} & -\frac{\nu_{31}}{E_3} & 0 & 0 & 0 \\ -\frac{\nu_{12}}{E_1} & \frac{1}{E_2} & -\frac{\nu_{32}}{E_3} & 0 & 0 & 0 \\ -\frac{\nu_{13}}{E_1} & -\frac{\nu_{23}}{E_2} & \frac{1}{E_3} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{23}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{31}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{21}} \end{bmatrix}$$



Gewebe

- Anisotropie (UD außerhalb der Hauptachse)
  → 21 unabh. Unbekannte



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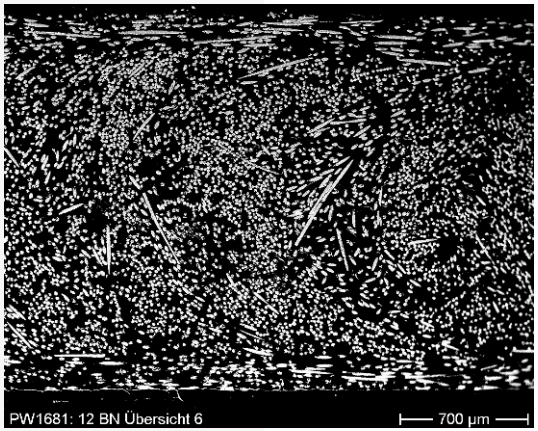
Kurz- und langfaserverstärkte Kunststoffe
Überblick

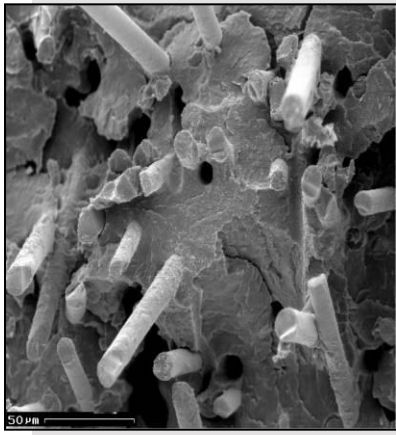
Einsatzgebiet (Automotive, Consumer Products, …)

Typische Thermoplaste (PA, PP, PBT, …)

Fasergehalt (GW 10-50%)

Typische Fasern (Glas, Kohle, …)





PA 6 unverstärkt
E=1300-3500 MPa (feucht – trocken)
σ=50-90MPa

PA 6 50% glasfaserverstärkt

nach Matls.com
E=9500-17500 MPa (feucht – trocken)
σ=120-240MPa

nach Honeywell.com
E=8900-16500 MPa (feucht – trocken)
σ=145-210MPa

mit Messdaten und Mikromechanik (orientierungsabhängig)

E_{Matrix}=2450 MPa E_{Faser}=70000 MPa $E_{Verbund}$ ~ 3000-15000MPa
σ_{Matrix}=80 MPa σ_{Faser}=3000 MPa $\sigma_{Verbund}$ ~ 90-220 MPa

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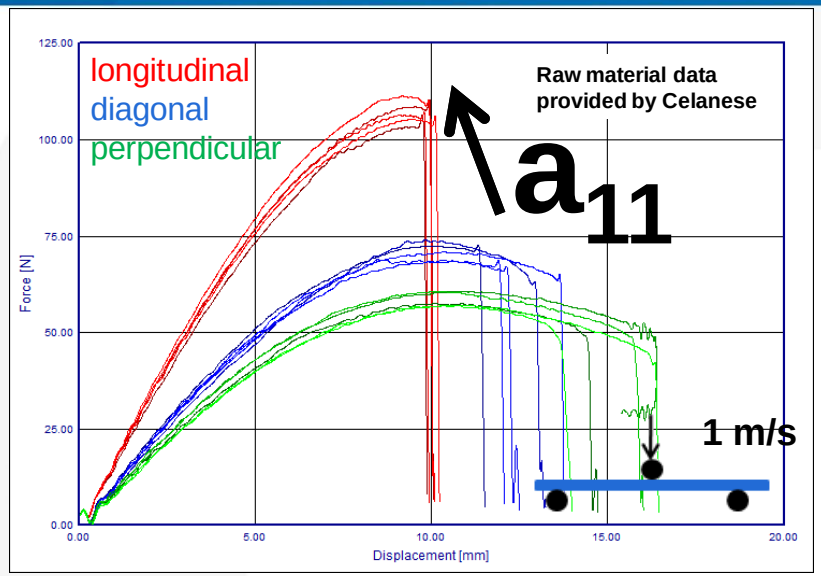
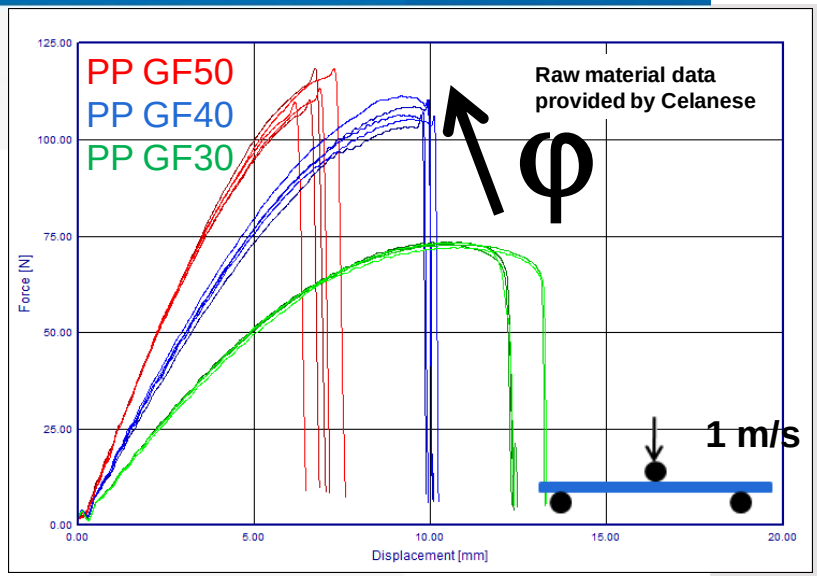
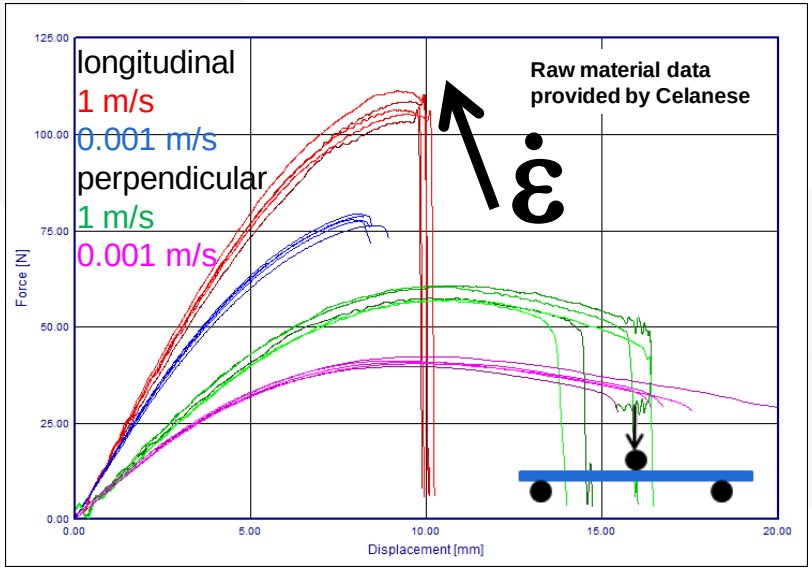
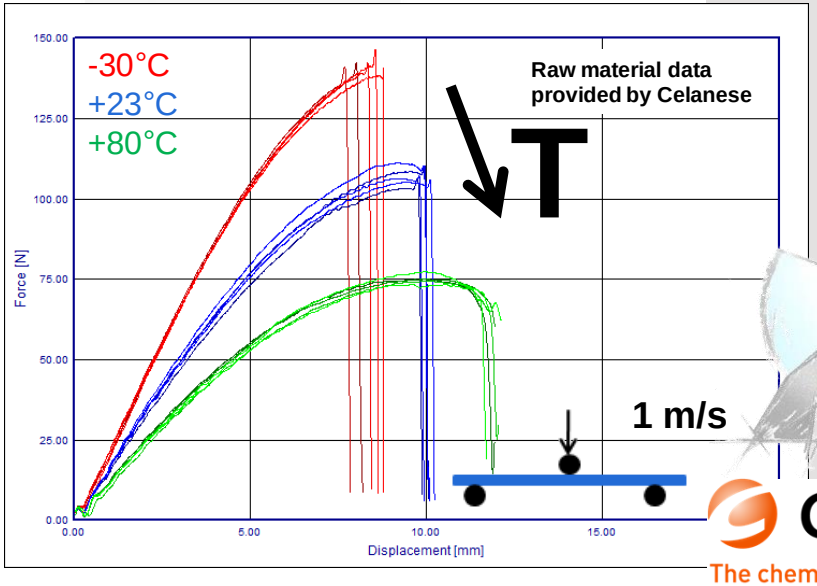
Kurz- und langfaserverstärkte Kunststoffe
Materialverhalten





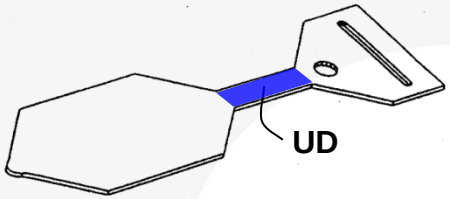


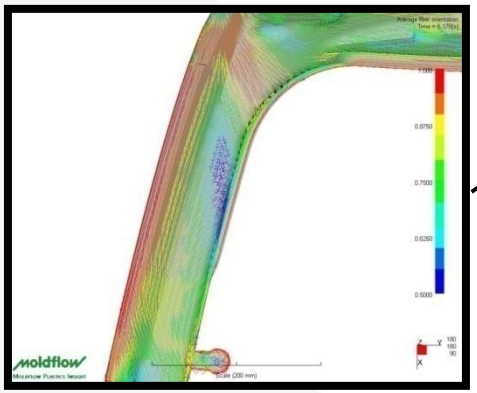


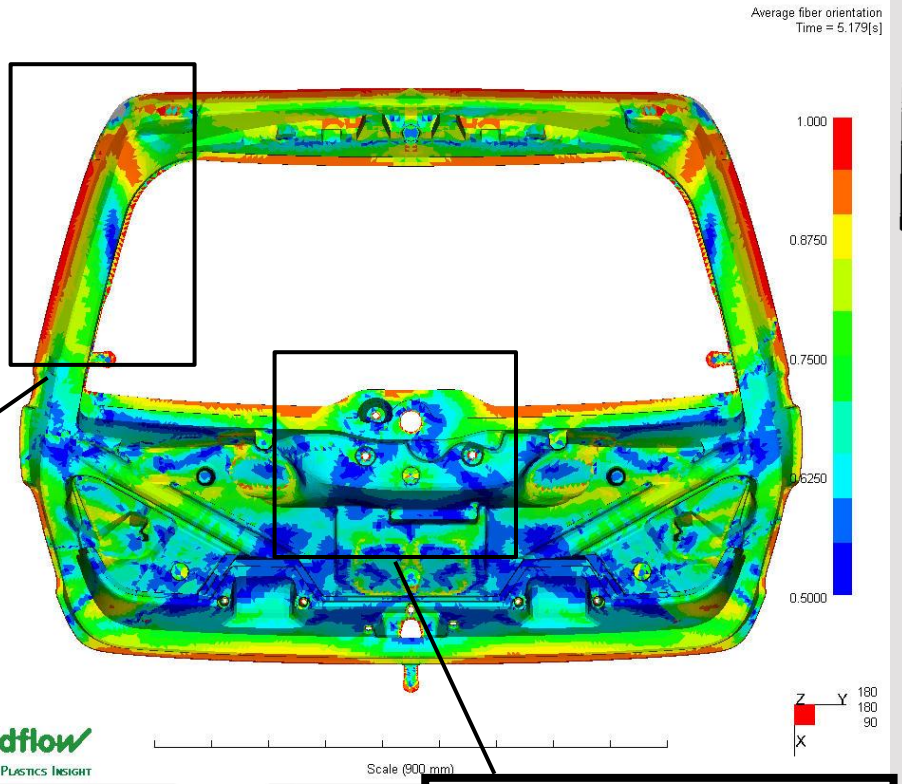
Celanese
The chemistry inside innovation™

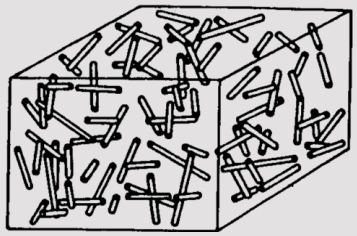
Kurz- und langfaserverstärkte Kunststoffe

Spritzguss



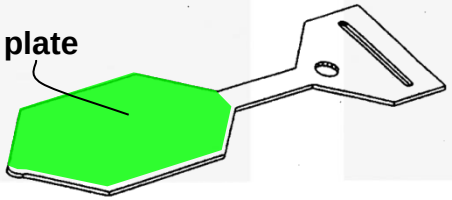


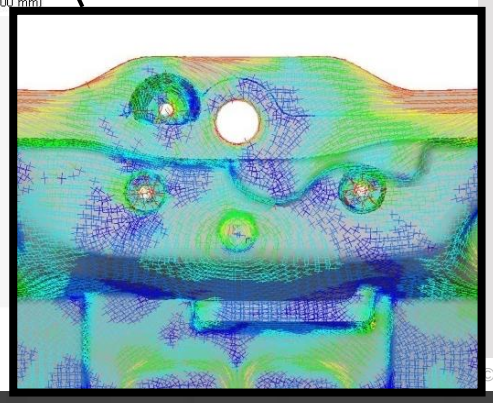




Kurzfaser

Analogie zu Platten-Bereich





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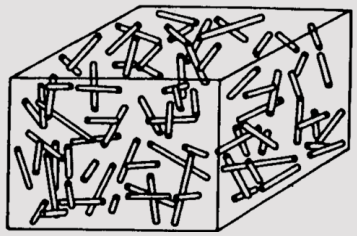
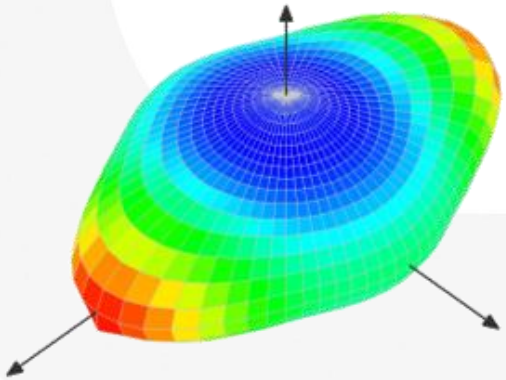


Kurzfaser

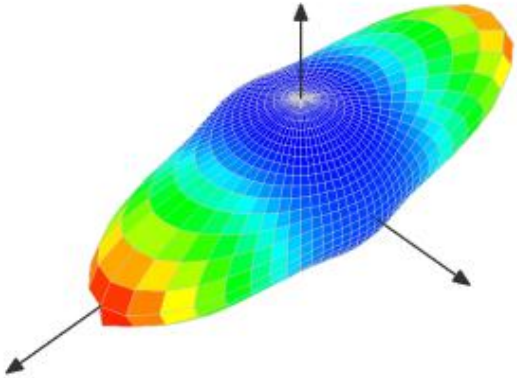
PA6 mit 30% Glasfaser (l/d 20)
(Gemittelte Faserorientierung)

Plattenbereich



$$a_{ij} = \begin{bmatrix} 0{,}66 & 0 & 0 \\ 0 & 0{,}32 & 0 \\ 0 & 0 & 0{,}02 \end{bmatrix}$$

Stegbereich



$$a_{ij} = \begin{bmatrix} 0{,}87 & 0 & 0 \\ 0 & 0{,}11 & 0 \\ 0 & 0 & 0{,}02 \end{bmatrix}$$

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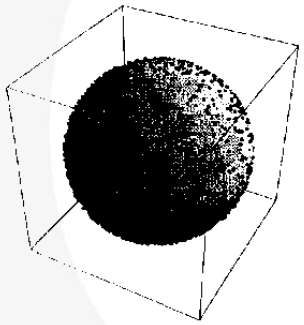
Kurz- und langfaserverstärkte Kunststoffe
Faserorientierung

Wahrscheinlichkeit eine Faser im Raum anzutreffen
typische Beschreibungsformen

Dichteanhäufung

$$a_{ij} = \oint \psi(p)\, p_i\, p_j\, dp$$



Tensor Global

$$a_{XX} + a_{YY} + a_{ZZ} = 1$$

$$\vec{x} \times \vec{y} = \vec{z}$$

$$a_{ij} = \begin{bmatrix} a_{XX} & a_{XY} & a_{XZ} \\ & a_{YY} & a_{YZ} \\ symm. & & a_{ZZ} \end{bmatrix}$$

Eigenwerte/-vektoren

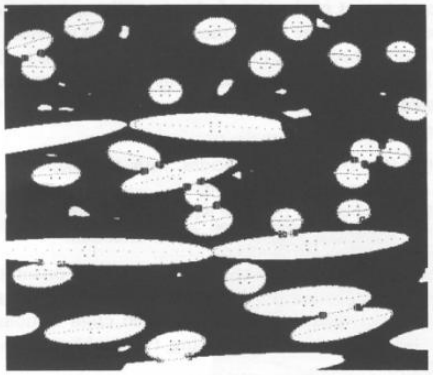
$$a_I + a_{II} + a_{III} = 1$$

$$\vec{v}_I \times \vec{v}_{II} = \vec{v}_{III}$$

$$a_{ij} = \begin{bmatrix} a_I & 0 & 0 \\ & a_{II} & 0 \\ symm. & & a_{III} \end{bmatrix}$$

Messung der Faserorientierung

- Schliffbilder (mehrere 1000 Fasern pro Messung)
- REM
- µ-CT



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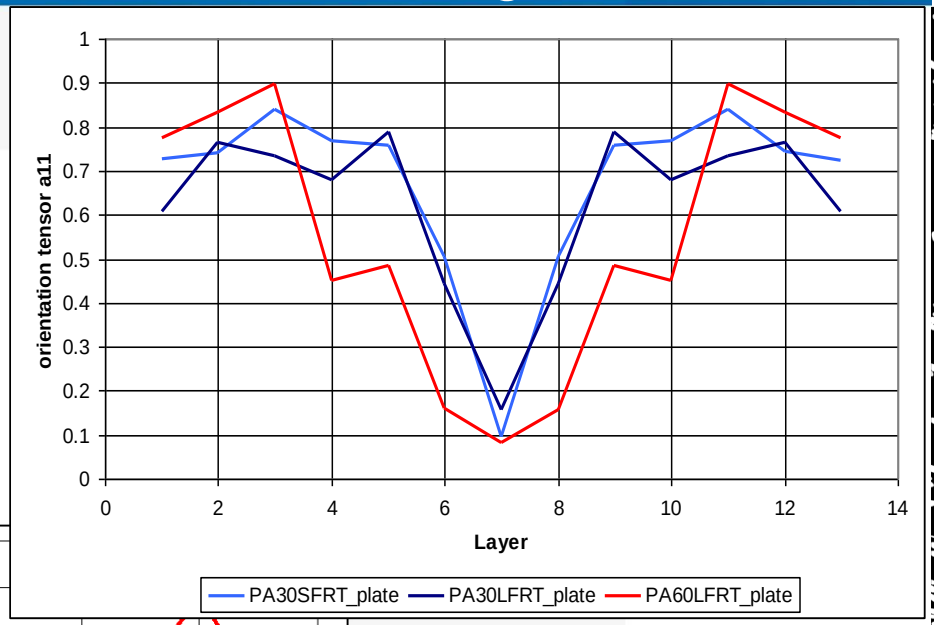
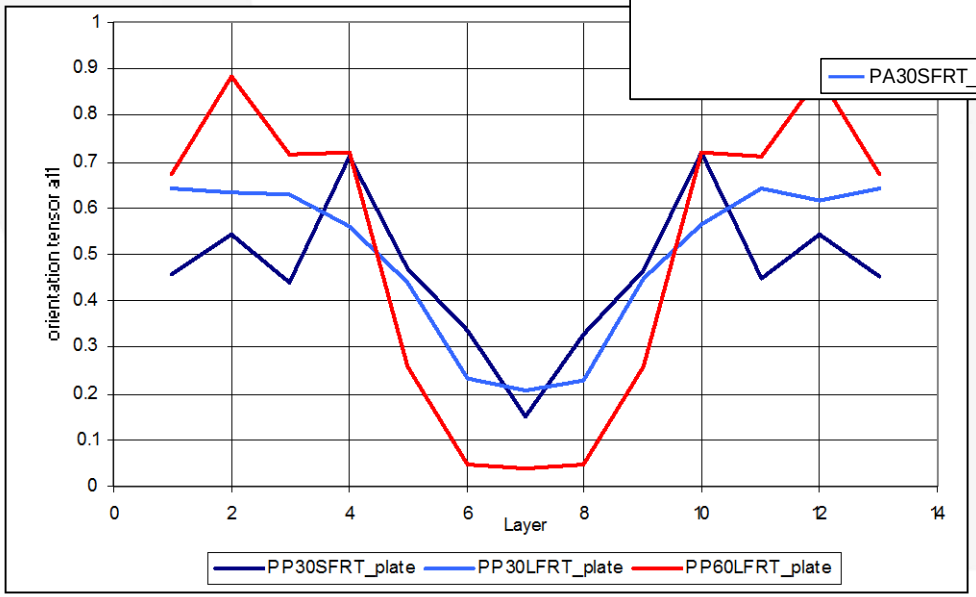
Kurz- und langfaserverstärkte Kunststoffe

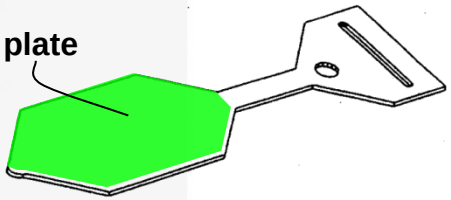
Vergleich gemessene Faserorientierung

Wechselwirkung

- Geometrie
  (Scher- vs. Quellströmung)
- Faserlänge
- Matrix (Viskosität)
- Fasergehalt (Interaktion)







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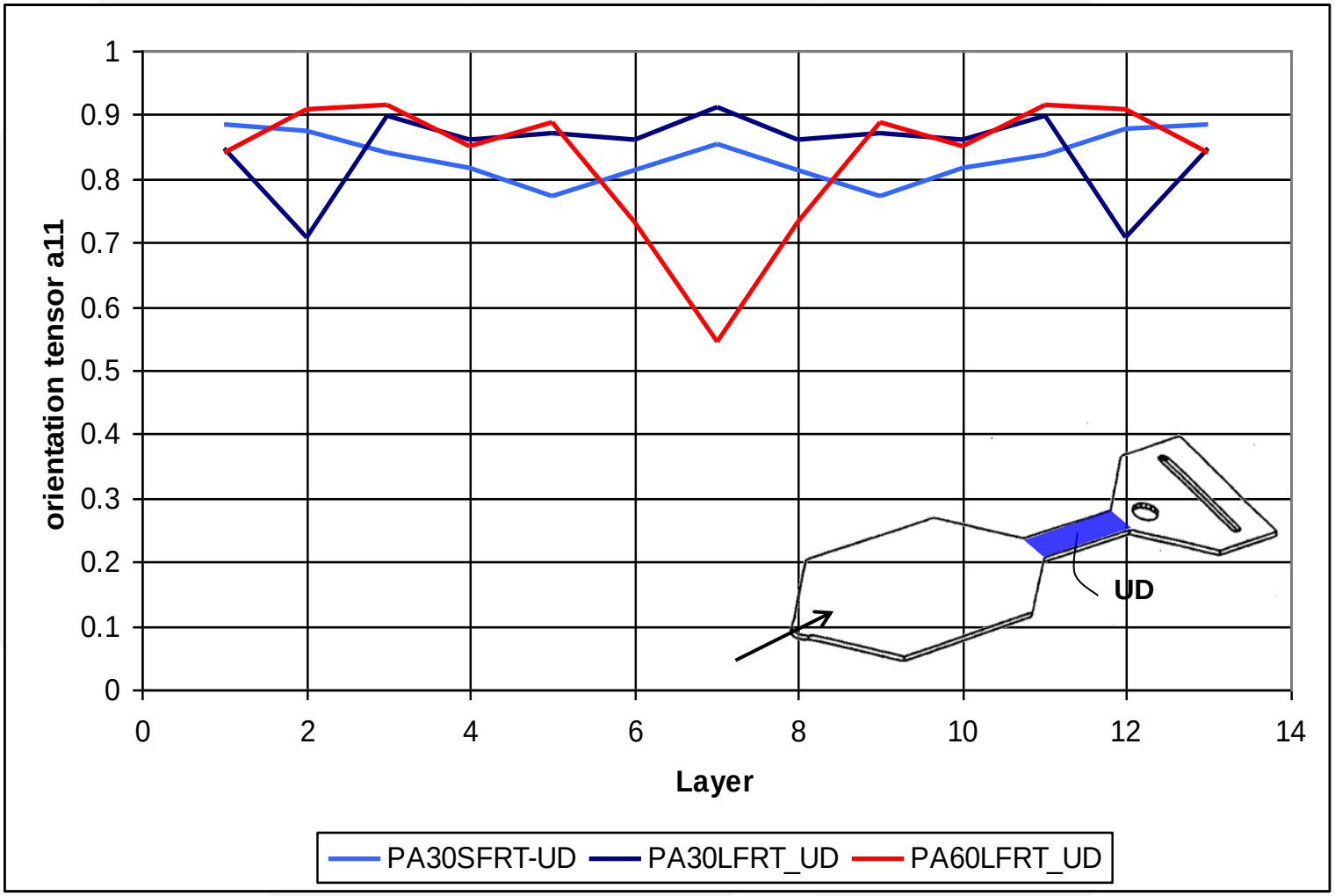
Kurz- und langfaserverstärkte Kunststoffe

Vergleich gemessene Faserorientierung



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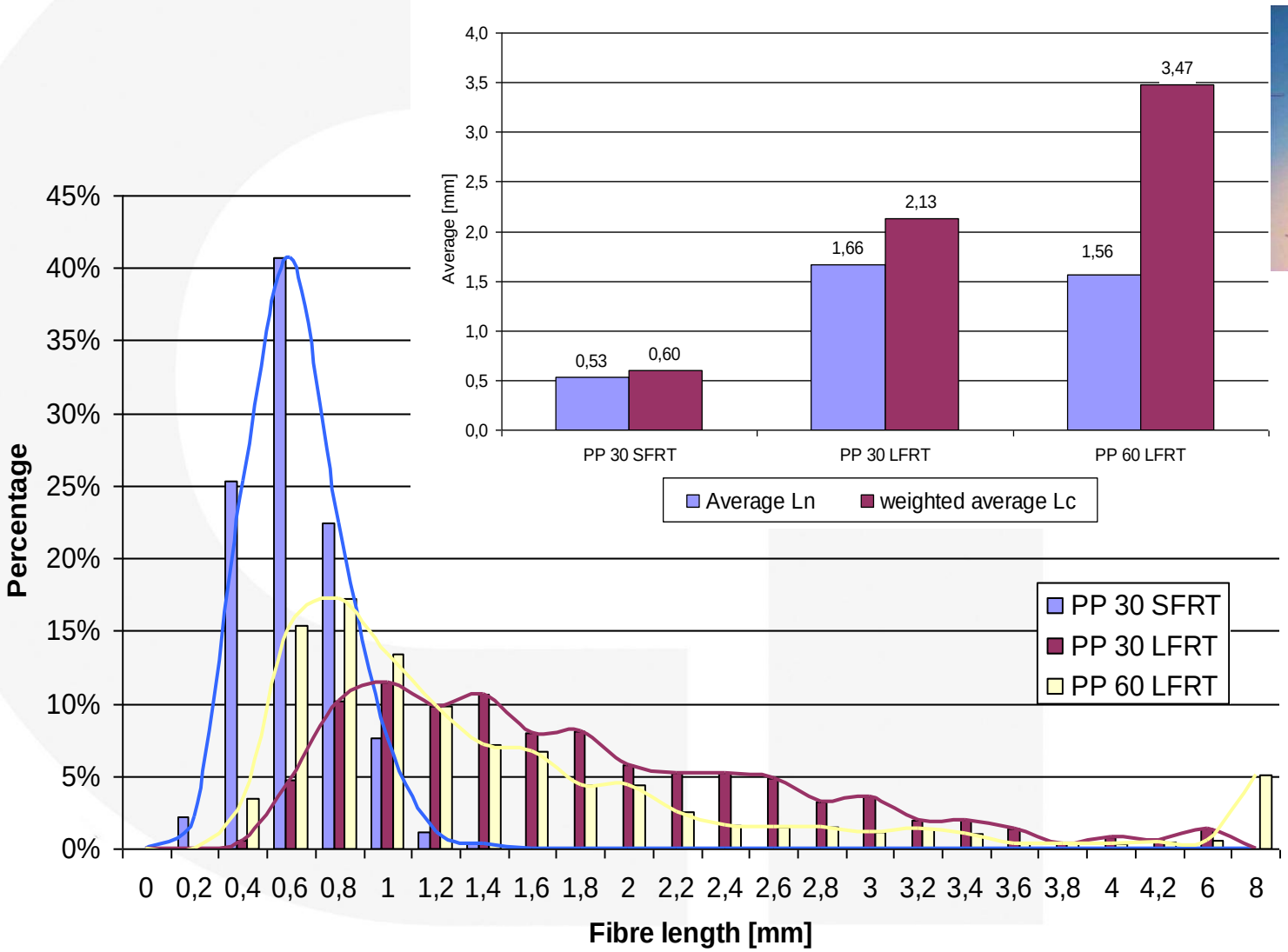
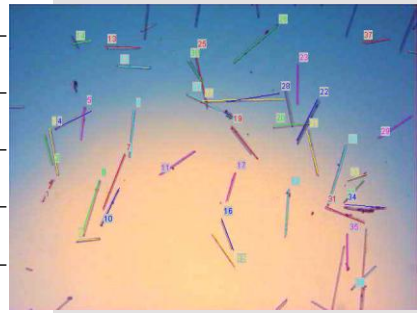
Kurz- und langfaserverstärkte Kunststoffe

Vergleich gemessene Faserlänge





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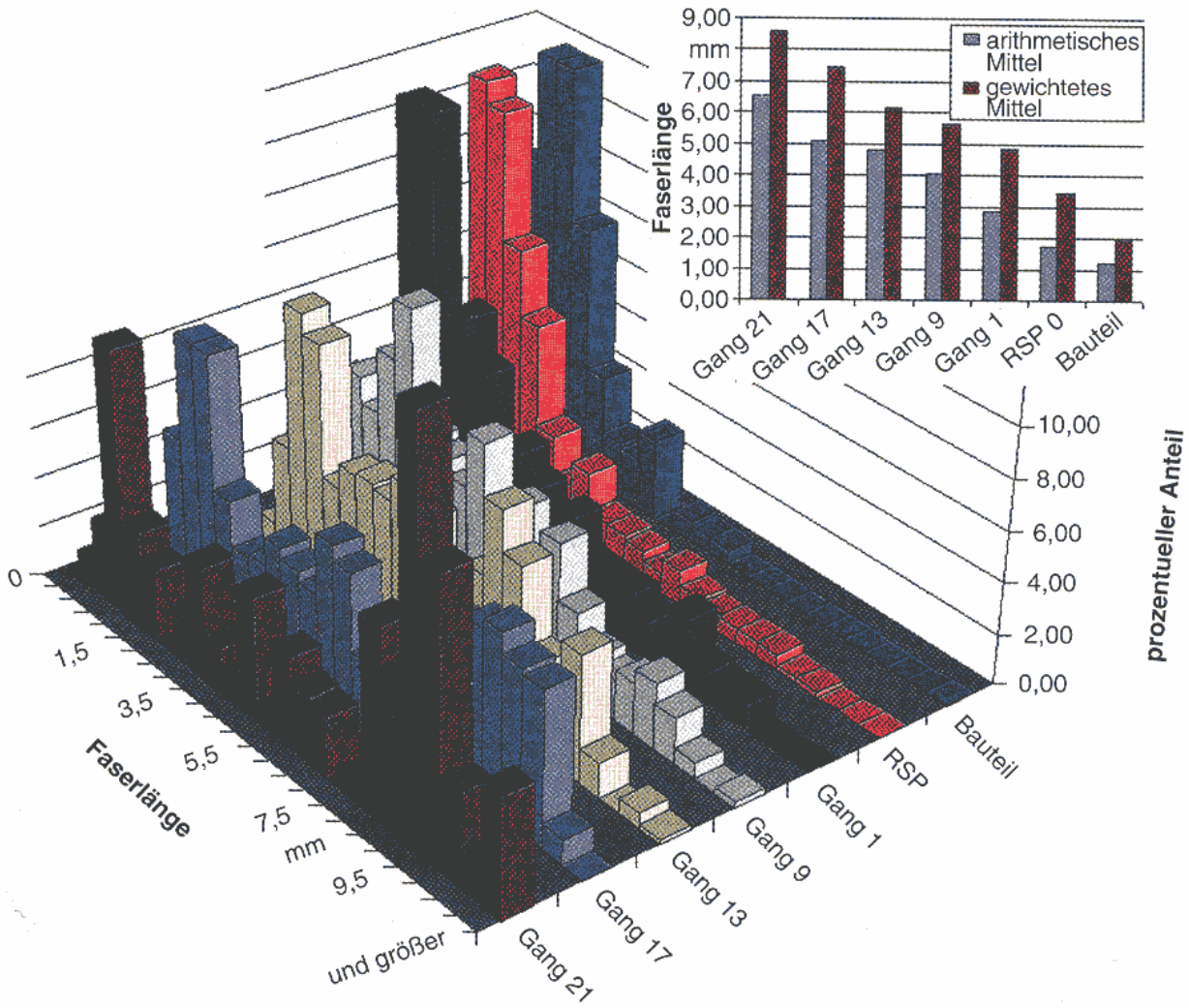
Kurz- und langfaserverstärkte Kunststoffe

Vergleich gemessene Faserlänge



Quelle: Kunststoffe Jahrg. 90 (200), Hanser Verlag

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Integrative Simulation
Simulationsprozess

Prozesssimulation

CADMOULD 3D-F SIMULATION

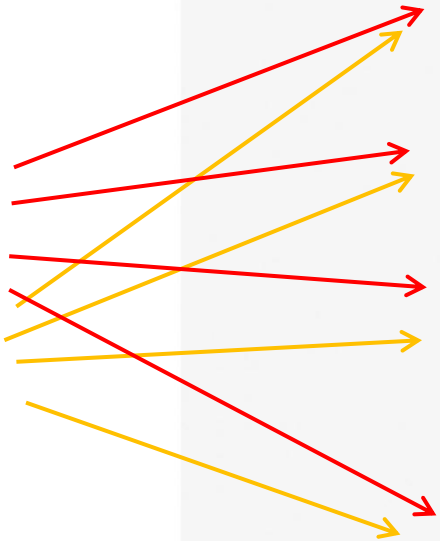
Moldex3D MOLDING INNOVATION

MOLDFLOW

SOLIDWORKS PLASTICS

SIGMASOFT

Schnittstellen am gleichen Netz



Übertragung der lokalen Richtungen oder Steifigkeiten

Struktursimulation

ANSYS

LS-DYNA

MSC Nastran

NX NASTRAN

AUTODESK NASTRAN

SIMULIA

Virtual Performance Solution

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Integrative Simulation
Simulationsprozess

Prozesssimulation

CADMOULD 3D-F SIMULATION

Moldex3D MOLDING INNOVATION

MOLDFLOW

SOLIDWORKS PLASTICS

SIGMASOFT

Mapping

digimat

4a FIBERMAP

EIGENE TOOLS

UNIVERSITÄRE TOOLS

Übertragung der lokalen Anisotropien

Struktursimulation

ANSYS

LS-DYNA

MSC Nastran

NX NASTRAN

AUTODESK NASTRAN

SIMULIA

Virtual Performance Solution

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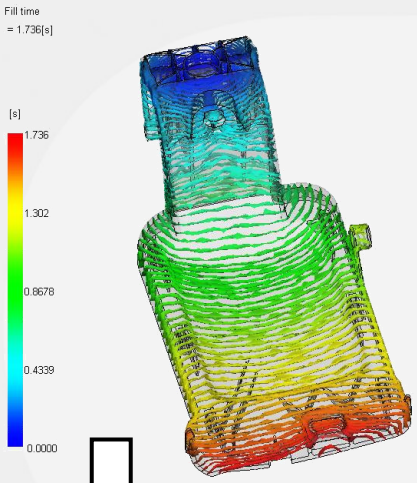
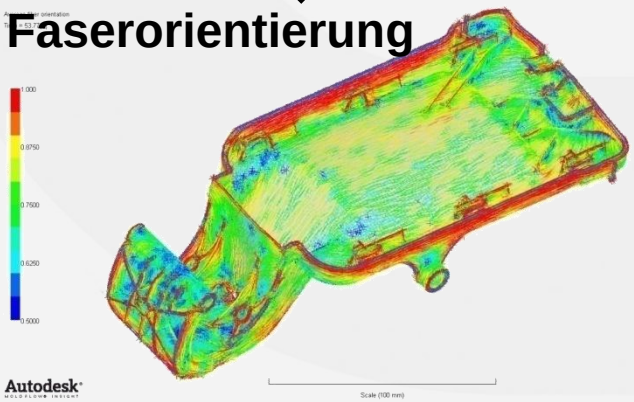
Integrative Simulation
Simulationsprozess

Prozesssimulation

Füllung

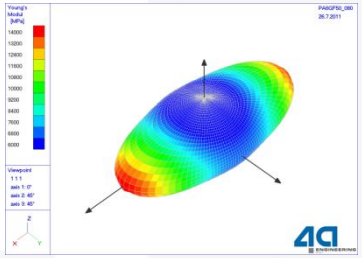


Faserorientierung



Mapping

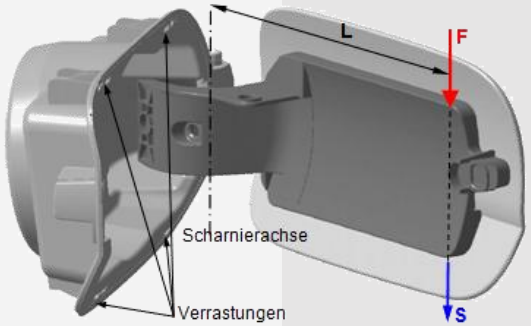
FIBERMAP

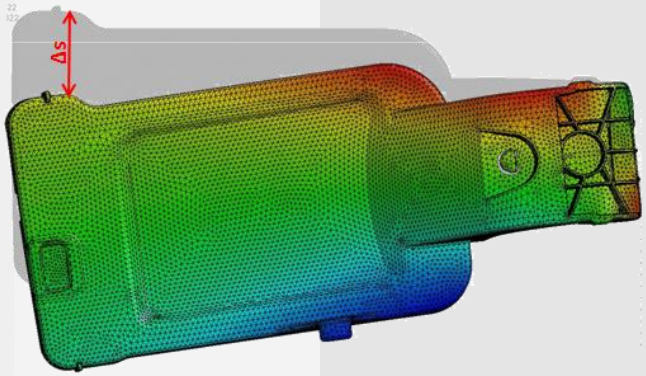


Übertragung der lokalen Anisotropien

Struktursimulation

Biegung





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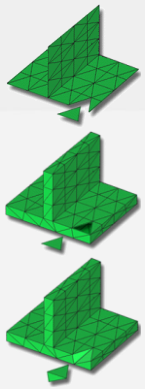
Integrative Simulation
Simulationsprozess

Prozesssimulation



Idealisierung

- 2 ½ D Mittelfläche
- 2 ½ D Oberfläche
- 3D Volumen

Strömung

- Viskosität
- pVT

Faser

- Faserlänge
- Faserdurchmesser

Faserorientierungsmodell

- Closure Approximations $OT^2 \rightarrow OT^4$
- Faserinteraktion (RSC, Ci, ARD, ..)
- Faserbruch

Mapping

Mittelungsverfahren

- Unterschiedliche Idealisierung
- Anzahl der Stützstellen

Schnittstellen

- Unterschiedlichste Softwarelösungen sowohl **prozess-** als auch **strukturseitig**

Transformationen

- Koordinatensysteme
- Ergebnisse (Vektor, Tensor)

....

Struktursimulation

Idealisierung

- Shell
- Solid
- Netzfeinheit, Integrationspunkte

Anwendung

- Verzug
- Bauteil (Steifigkeit, Festigkeit)
- Crash (Energie, Versagen)

Materialmodell

- SOLVER, USERMATERIALS
- Geschwindigkeit, Feuchte, Temp.

Orientierung

- Global
- Elementweise

Vielzahl an Vorgehensweisen & Einstellmöglichkeiten

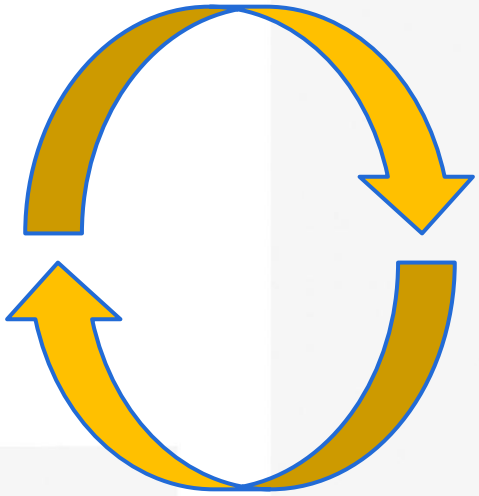
Validierung der gesamten Prozesskette erforderlich

Integrative Simulation
Informationsfluss

Anwendungs-experte

Spritzgießer

Konstrukteur



Werkzeugmacher

Simulationsexperte (Struktur)

Simulationsexperte (Prozess)

R&D

Material-hersteller

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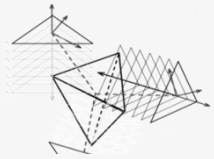
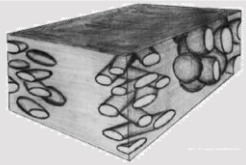
4a Softwaretools
Übersicht

4a ENGINEERING GmbH

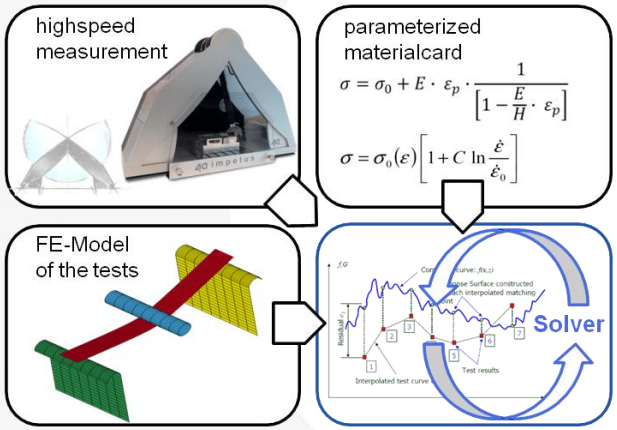
4a IMPETUS

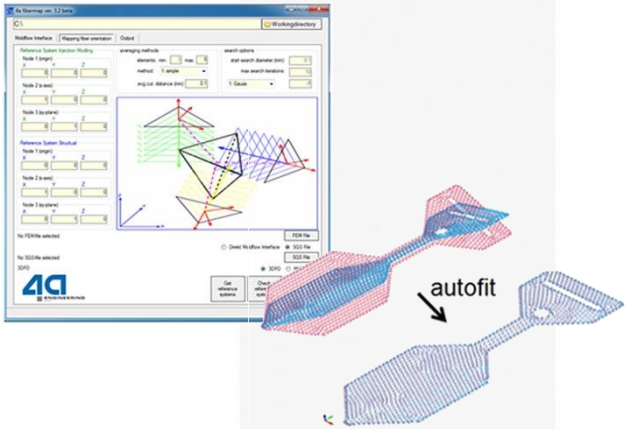


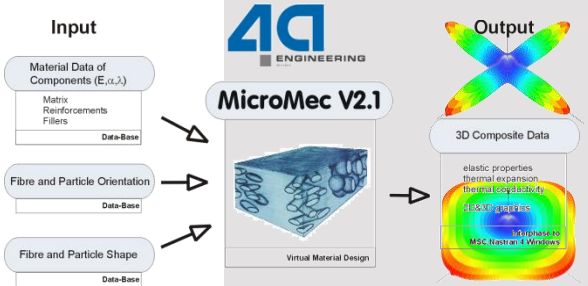
4a FIBERMAP



4a MICROMEC







Validierte Materialkarten
Nachvollziehbarer Prozess

Individuelles Mapping
von Prozessinformationen

3D thermoelastische
anisotrope Materialkarten

Virtual Performance Solution | LS-DYNA | SIMULIA

MOLDFLOW | Moldex3D MOLDING INNOVATION | LS-DYNA

NASTRAN | LS-DYNA | SIMULIA | Virtual Performance Solution

NASTRAN | LS-DYNA | SIMULIA | Virtual Performance Solution

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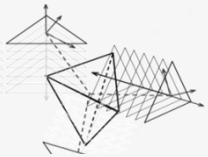
4a Softwaretools
Neuerungen

4a IMPETUS

4a FIBERMAP



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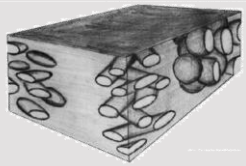
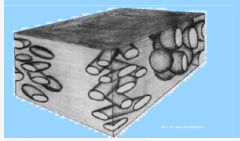




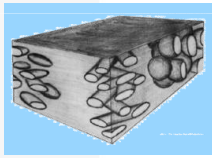
4a micromec Library

orthotrope Standardmaterialkarten elastisch viskoplastisch (HILL Plastizität)

Virtual Performance Solution

LS-DYNA

SIMULIA



internes Usermaterial elastisch viskoplastisch

LS-DYNA

SIMULIA

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