Hochschule Aalen

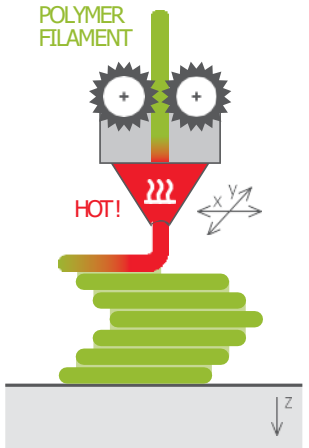
Prozess - Struktur gekoppelte Simulation additiv gefertigter Kunststoffe

Fabian Ferrano / Jan Hertel

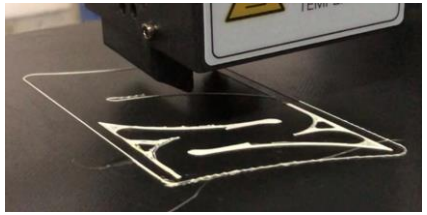
Agenda

- Fused Layer Manufacturing (FLM) Verfahren
- Prozess - Struktur gekoppelte Simulation
- Gegenüberstellung von Simulations- und Versuchsergebnissen
- Fazit und Ausblick

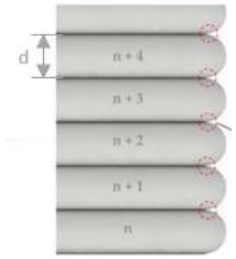
Fused Layer Manufacturing (FLM) Verfahren



- Die additive Fertigung (AM) hat sich in den letzten Jahren zu einem immer beliebteren Verfahren entwickelt [1], nicht nur in der Industrie, sondern auch in der Privatwirtschaft [2].



- In jüngster Zeit werden FLM-Verfahren, auch bekannt als Fused Deposition Modeling (FDM: geschützte Marke), zunehmend in technischen Bereichen eingesetzt [3].



- Mechanischen Eigenschaften der 3D-gedruckten Komponenten müssen genau bekannt sein.

- Mit dem Ziel: Jeden Anwendungsbereich zu bedienen.

[1] „Additive manufacturing (3D printing): A review of materials, methods, applications and challenges,“ Composites Part B: Engineering, Bd. 143, pp. 172-196, 2018.; [2] A. G. Miranda Fateri, Introduction to Additive Manufacturing, Springer Series in Optical Sciences , 2020. ; [3] J. K. L. T. Andreas Gebhardt, 3D Printing Understanding Additive Manufacturing, München: Carl Hanser Verlag, 2019.

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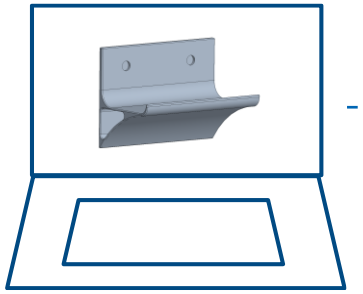
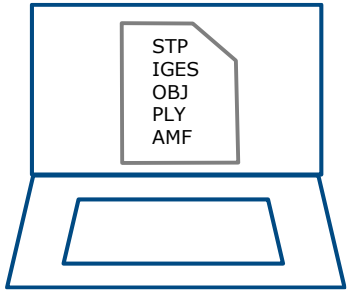
Produktentstehungsprozess

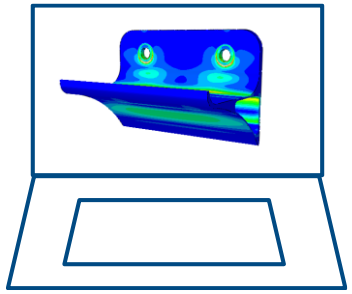
Entwicklungsphase



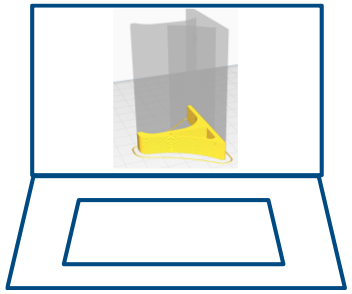
Konstruktion / CAD



Dateiverwaltung



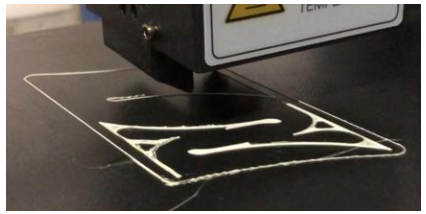
Simulation / FEM



Prozess-Parameter

Herstellung

Herstellungs-Code



Herstellung

Nachbearbeitung

Nachbearbeitung / Qualitätskontrolle

Fertiges Bauteil

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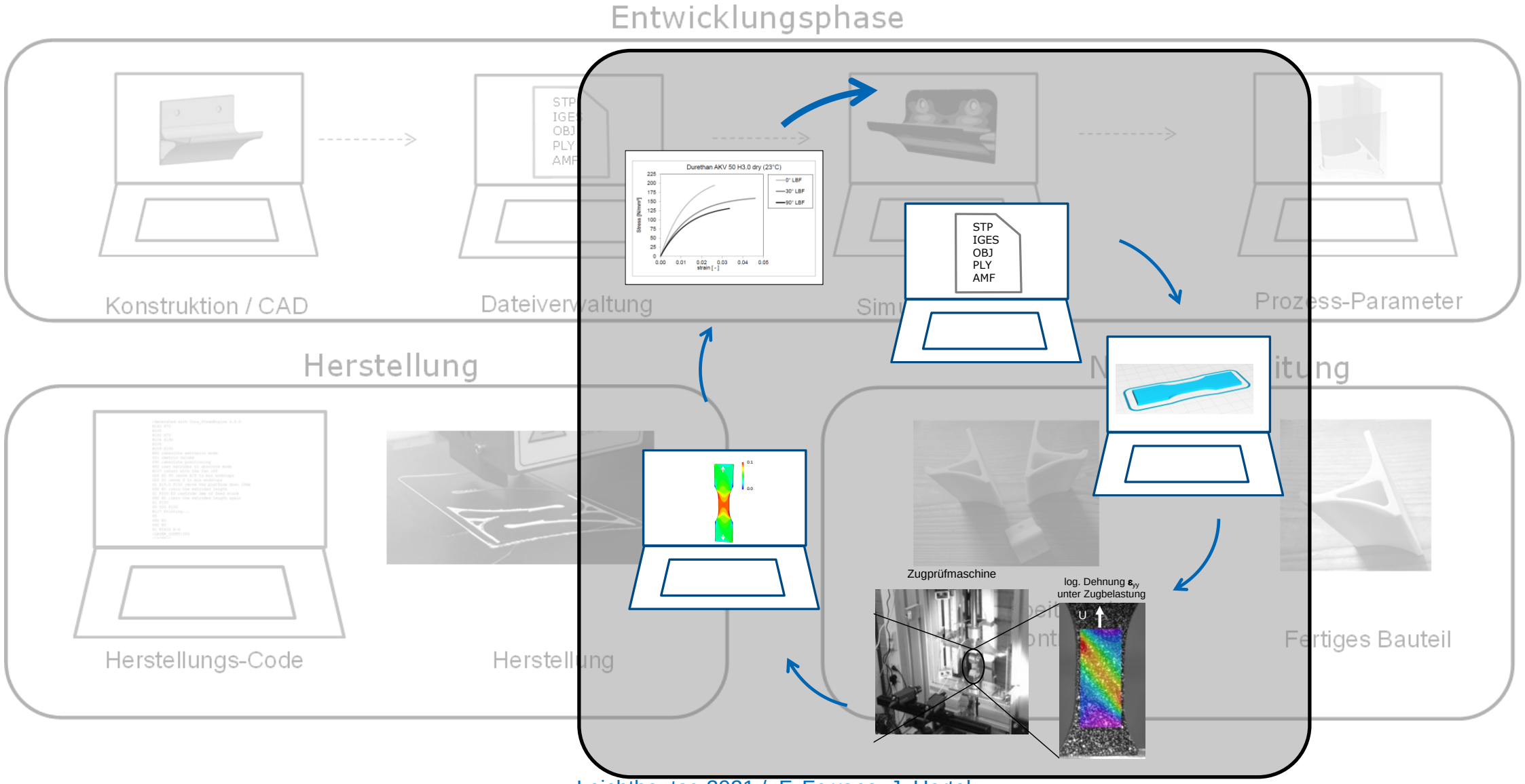
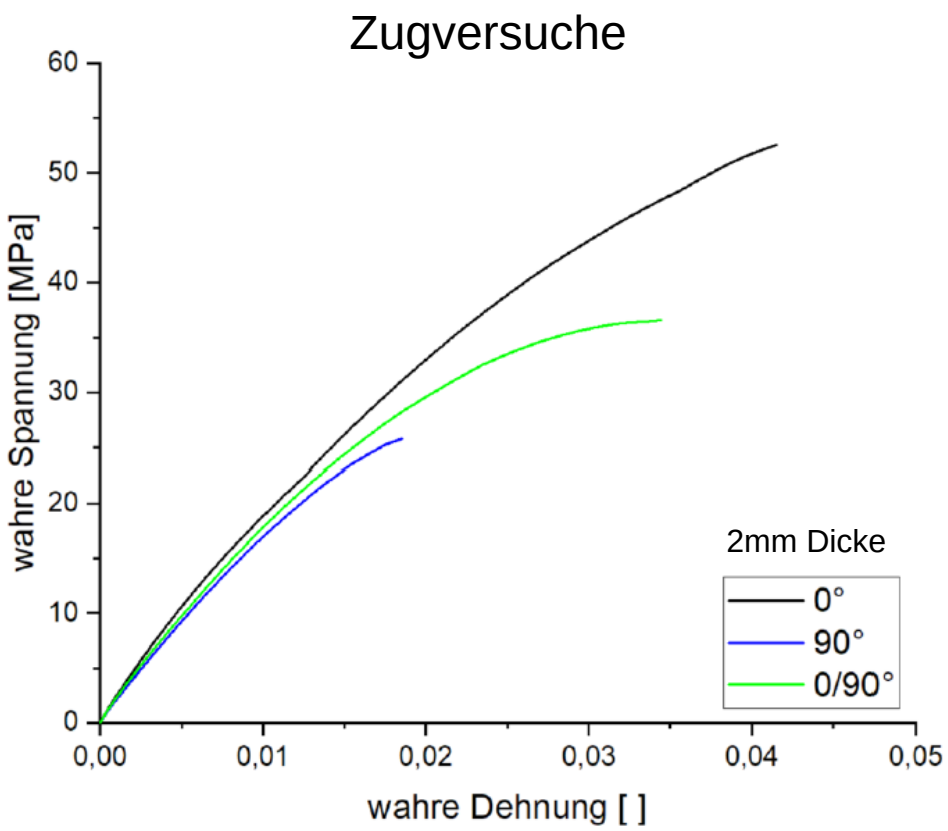
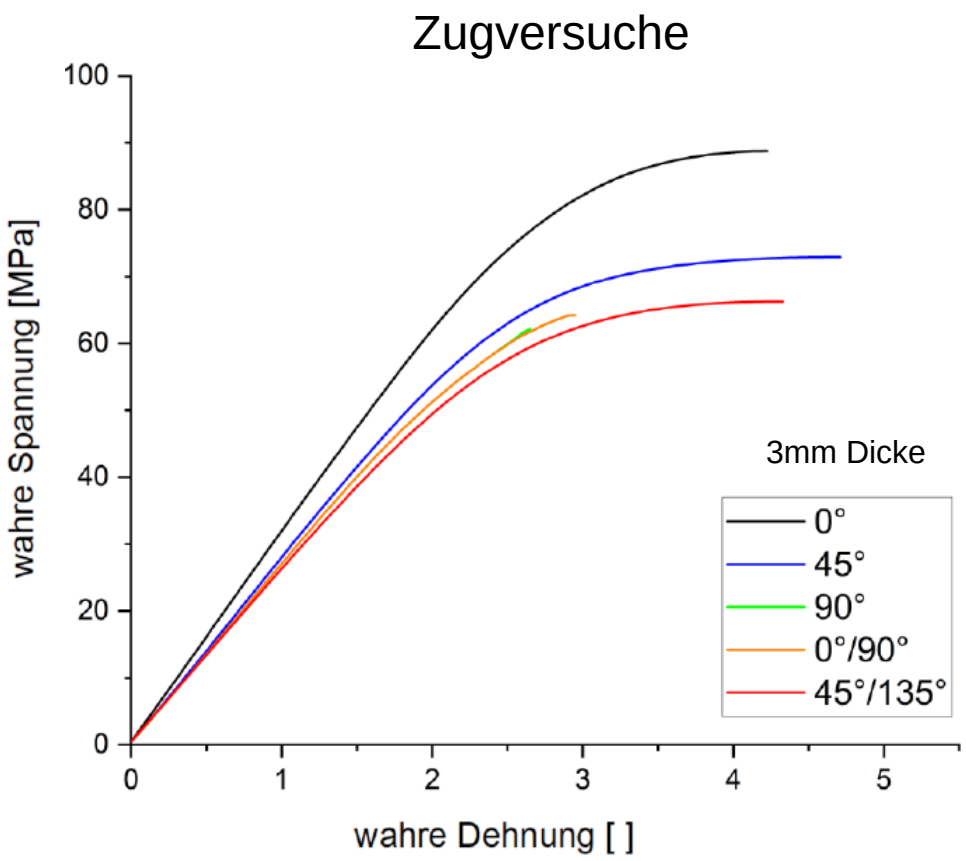
Produktentstehungsprozess

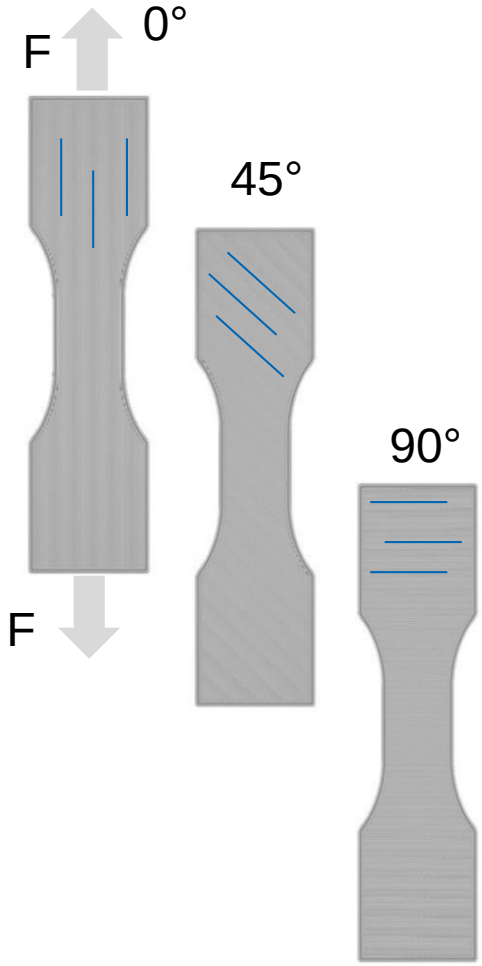


Mechanischen Eigenschaften

- FLM – Verfahren: strangförmiger und schichtweiser Aufbau
- Anisotropes und elastoplastisches Werkstoffverhalten

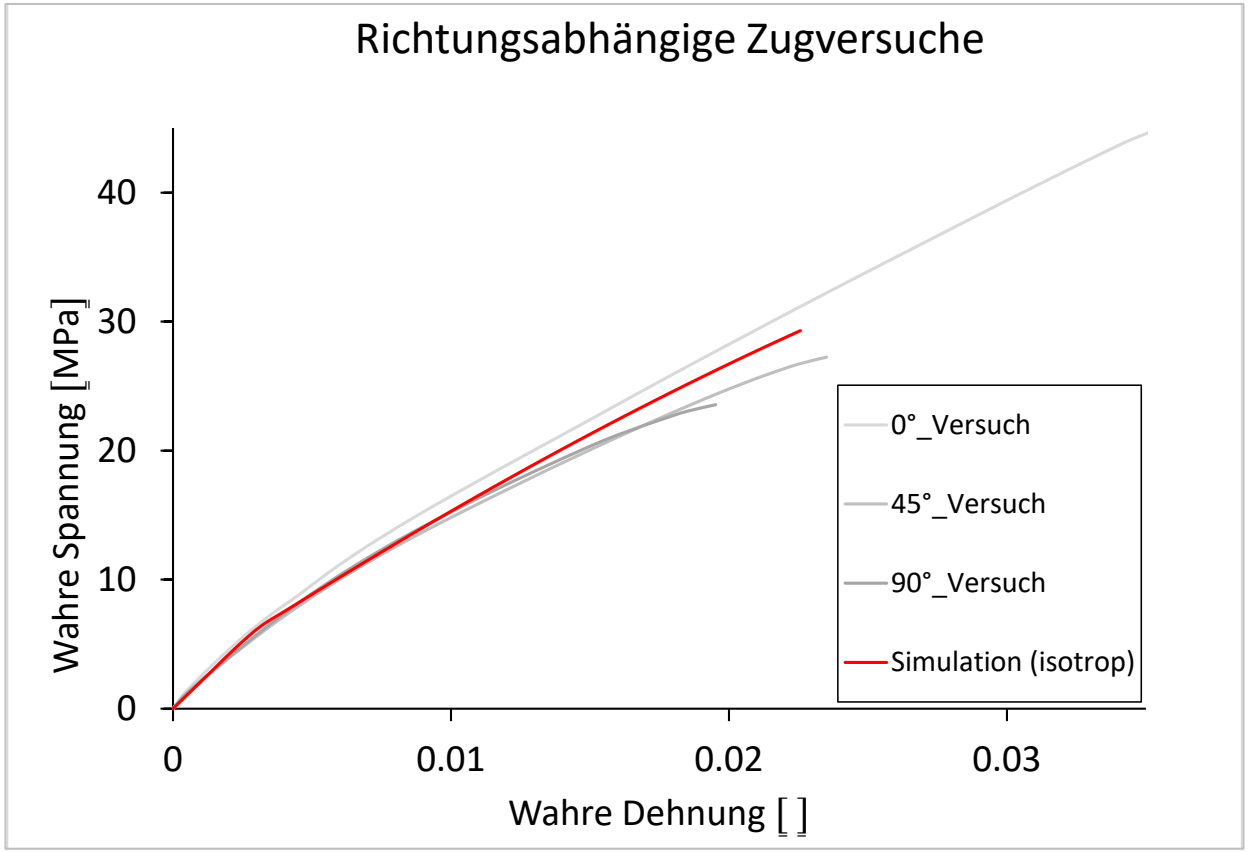


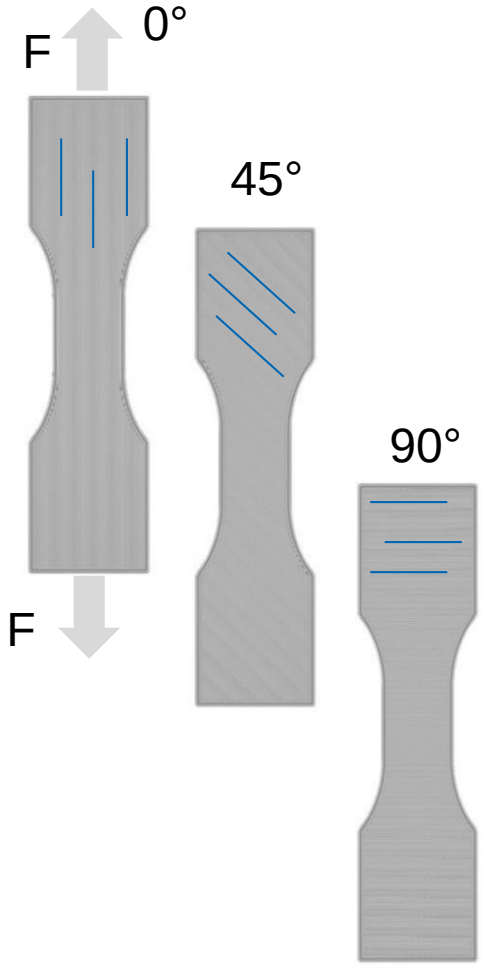




Mechanischen Eigenschaften / Simulation

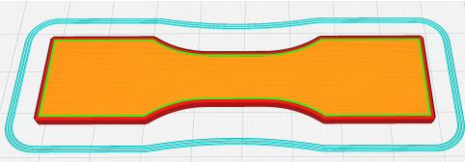
- Das Werkstoffverhalten ist mit einem einfachem Materialmodell in der Simulation nicht abbildbar



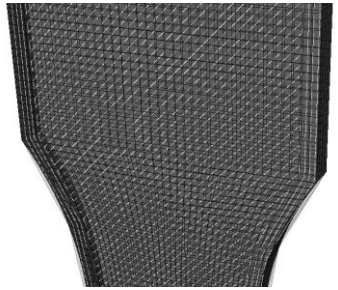


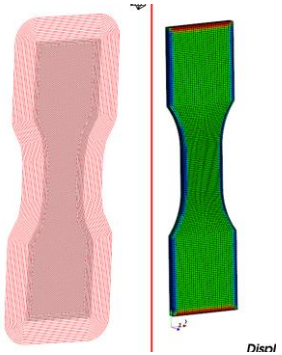
Prozessschritte

Prozesssimulation

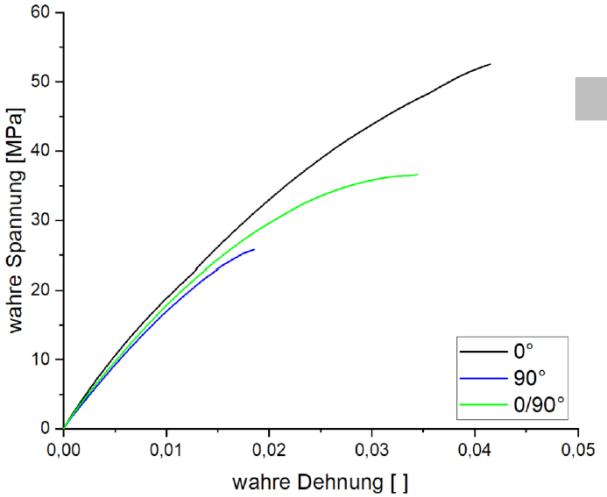


Mapping

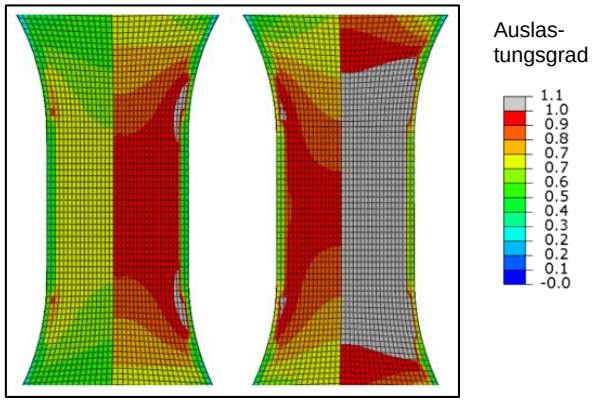




Materialmodellierung



Strukturberechnung



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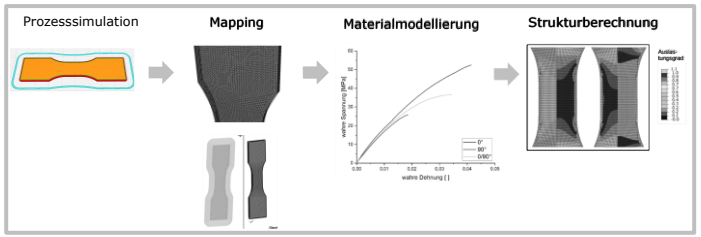
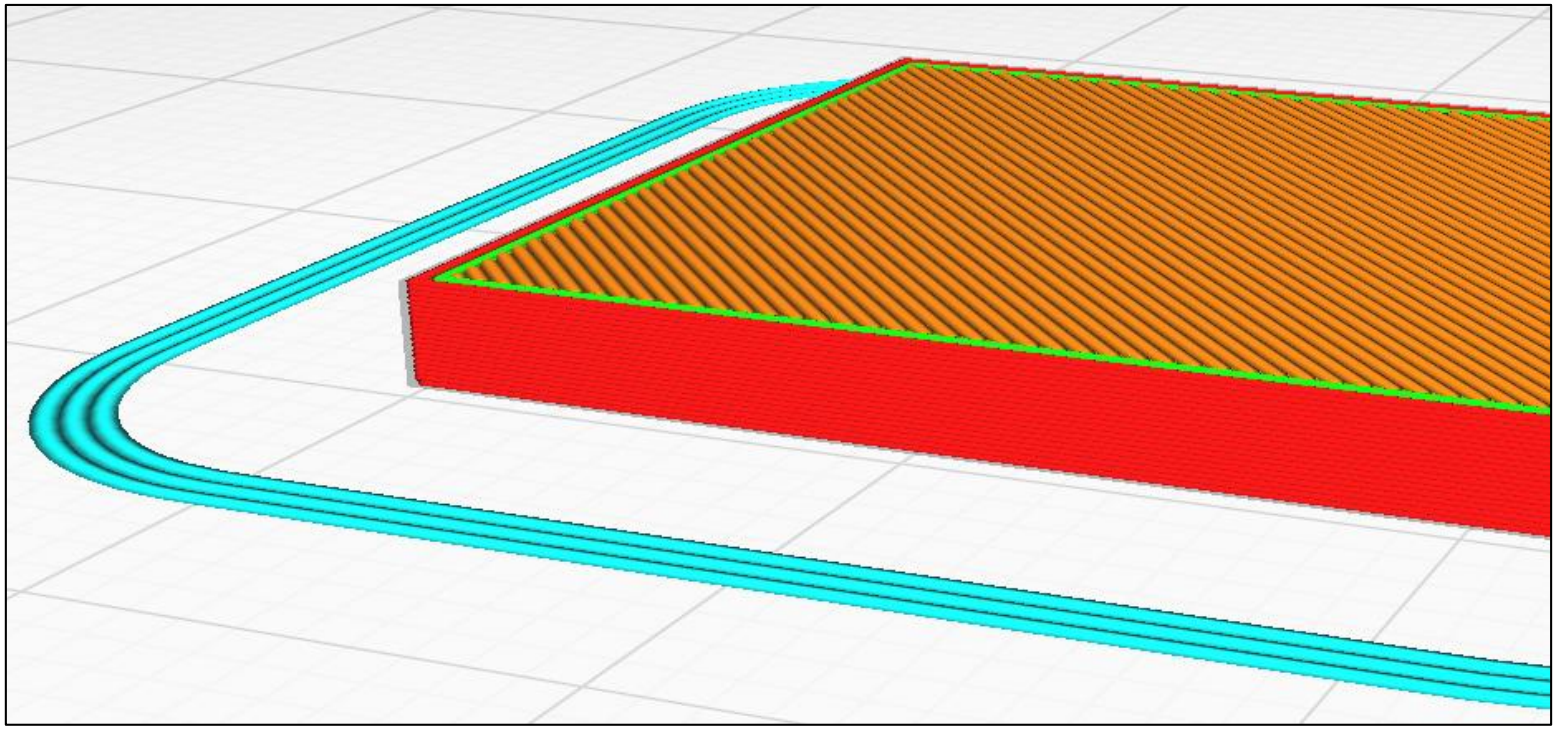
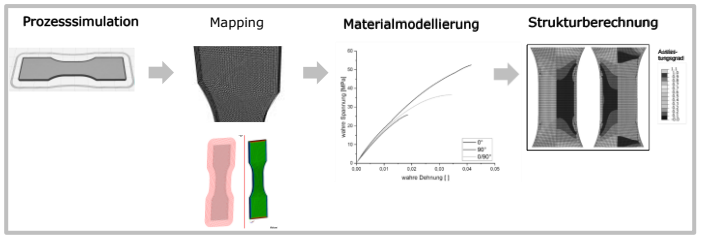


Prozesssimulation (Slicing)

- Bestimmung der Prozessparameter
- Positionierung
- G-Code Generierung

```
;Generated with Cura_SteamEngine 4.8.0
M140 S70
M105
M190 S70
M104 S190
M105
M109 S190
M82 ;absolute extrusion mode
G21 ;metric values
G90 ;absolute positioning
M82 ;set extruder to absolute mode
M107 ;start with the fan off
G28 X0 Y0 ;move X/Y to min endstops
G28 Z0 ;move Z to min endstops
G1 Z15.0 F150 ;move the platform down 15mm
```





Mapping

- Übertragung der Richtungsinformation des G-Codes auf das Strukturnetz (FEM-Modell)

```
;Generated with Cura_SteamEngine 4.8.0
M140 S70
M105
M190 S70
M104 S190
M105
M109 S190
M82 ;absolute extrusion mode
G21 ;metric values
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```
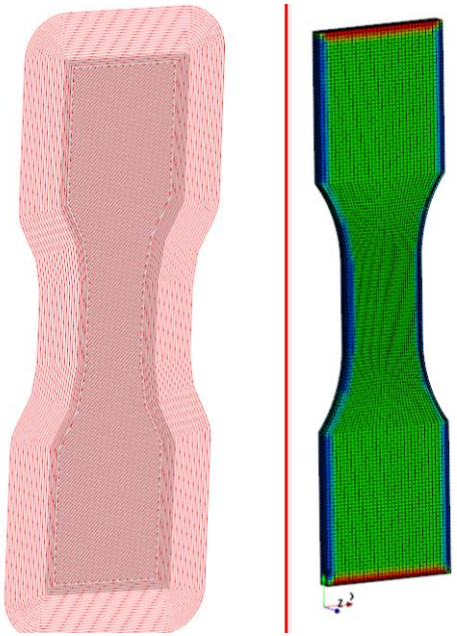
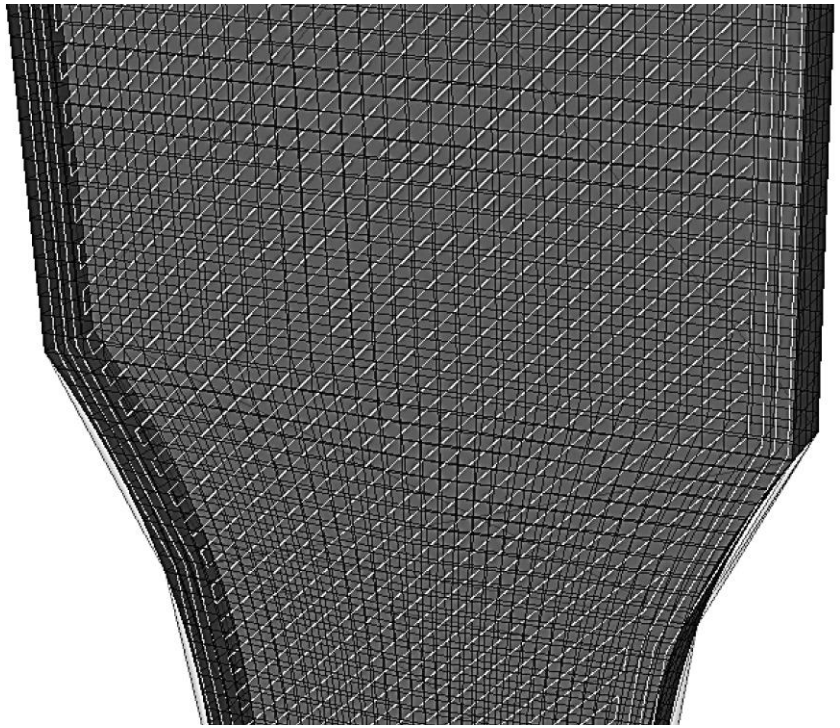
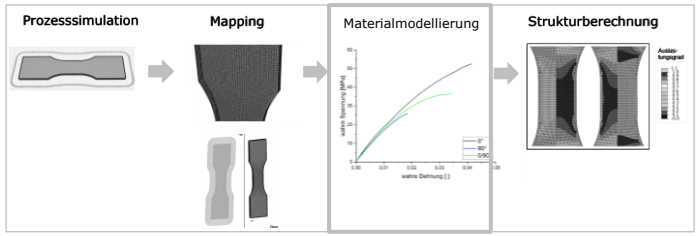





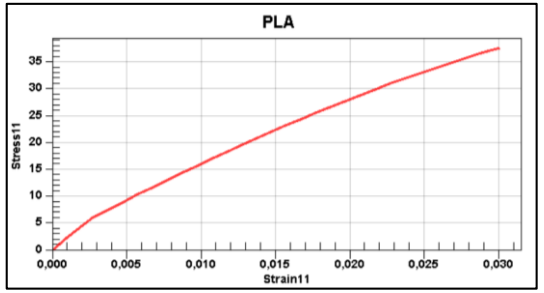
Hochschule Aalen



Materialmodellierung

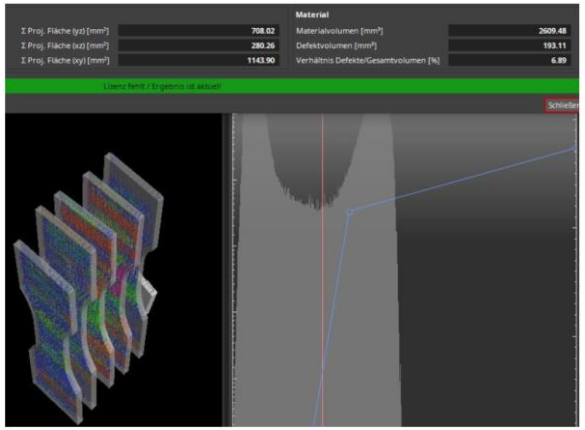
- Lokales Materialverhalten unter Berücksichtigung der Porosität, der Festigkeit zwischen den Schichten und dem elastoplastischen Werkstoffverhalten.

Mikromechanik: Porosität, Plastizität (Digimat MF), Richtungsabhängigkeit

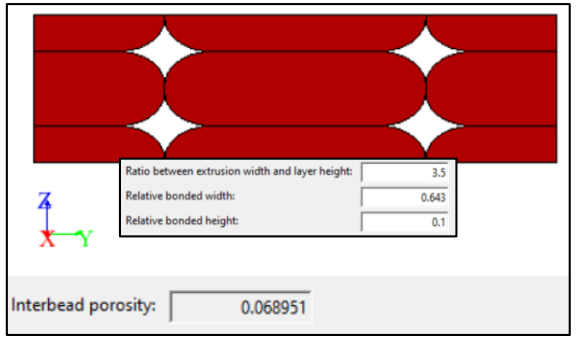


Elastoplastisches Materialverhalten

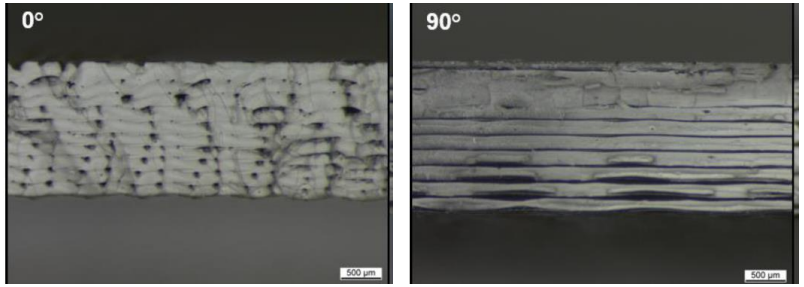
Bestimmung der Porosität mittels CT-Messung



Richtungsabhängigkeit



Porosität von Zugprüfstäben in 0°- und 90° Ablegerichtung



/ Numerical simulation of additive manufacturing of polymers and polymer-based composites, Laurent Adam et al., Structure and Properties of Additive Manufactured Polymer Components 2020 Elsevier /

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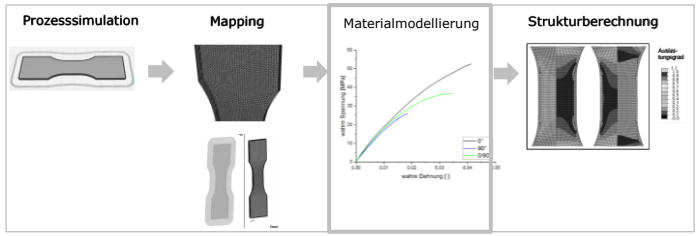
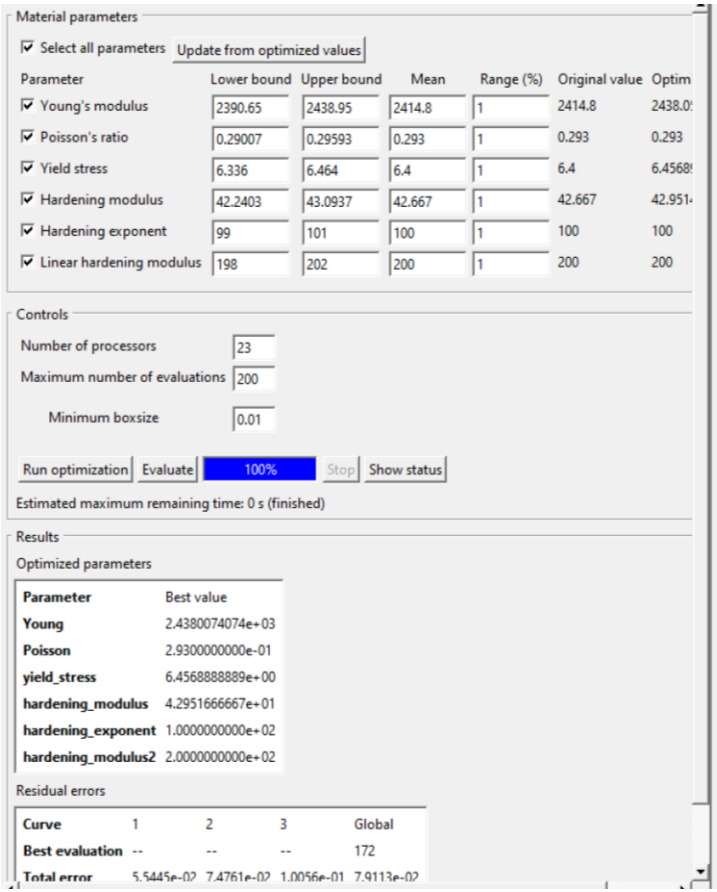
Materialmodellierung



- Reverse Engineering (0°, 45° und 90°)
- Automatisierter Anpassungsprozess
- Anpassung von 7 Größen
- Beschreibung des anisotropen elastoplastischen Werkstoffverhaltens



Material parameters

Select all parameters | Update from optimized values

Parameter	Lower bound	Upper bound	Mean	Range (%)	Original value	Optim
Young's modulus	2390.65	2438.95	2414.8	1	2414.8	2438.0
Poisson's ratio	0.29007	0.29593	0.293	1	0.293	0.293
Yield stress	6.336	6.464	6.4	1	6.4	6.4568
Hardening modulus	42.2403	43.0937	42.667	1	42.667	42.951
Hardening exponent	99	101	100	1	100	100
Linear hardening modulus	198	202	200	1	200	200

Controls

Number of processors: 23

Maximum number of evaluations: 200

Minimum boxsize: 0.01

Run optimization | Evaluate | 100% | Stop | Show status

Estimated maximum remaining time: 0 s (finished)

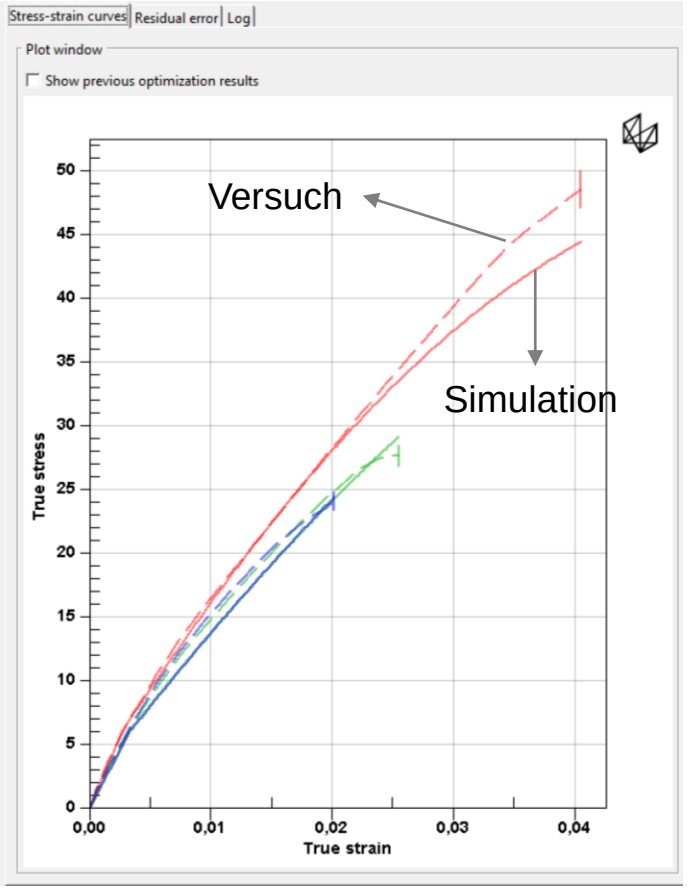
Results

Optimized parameters

Parameter	Best value
Young	2.4380074074e+03
Poisson	2.9300000000e-01
yield_stress	6.4568888889e+00
hardening_modulus	4.2951666667e+01
hardening_exponent	1.0000000000e+02
hardening_modulus2	2.0000000000e+02

Residual errors

Curve	1	2	3	Global
Best evaluation	--	--	--	172
Total error	5.5445e-02	7.4761e-02	1.0056e-01	7.9113e-02



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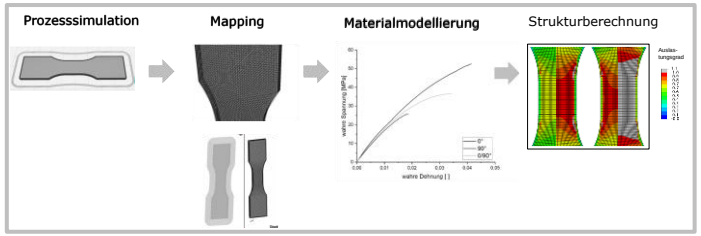
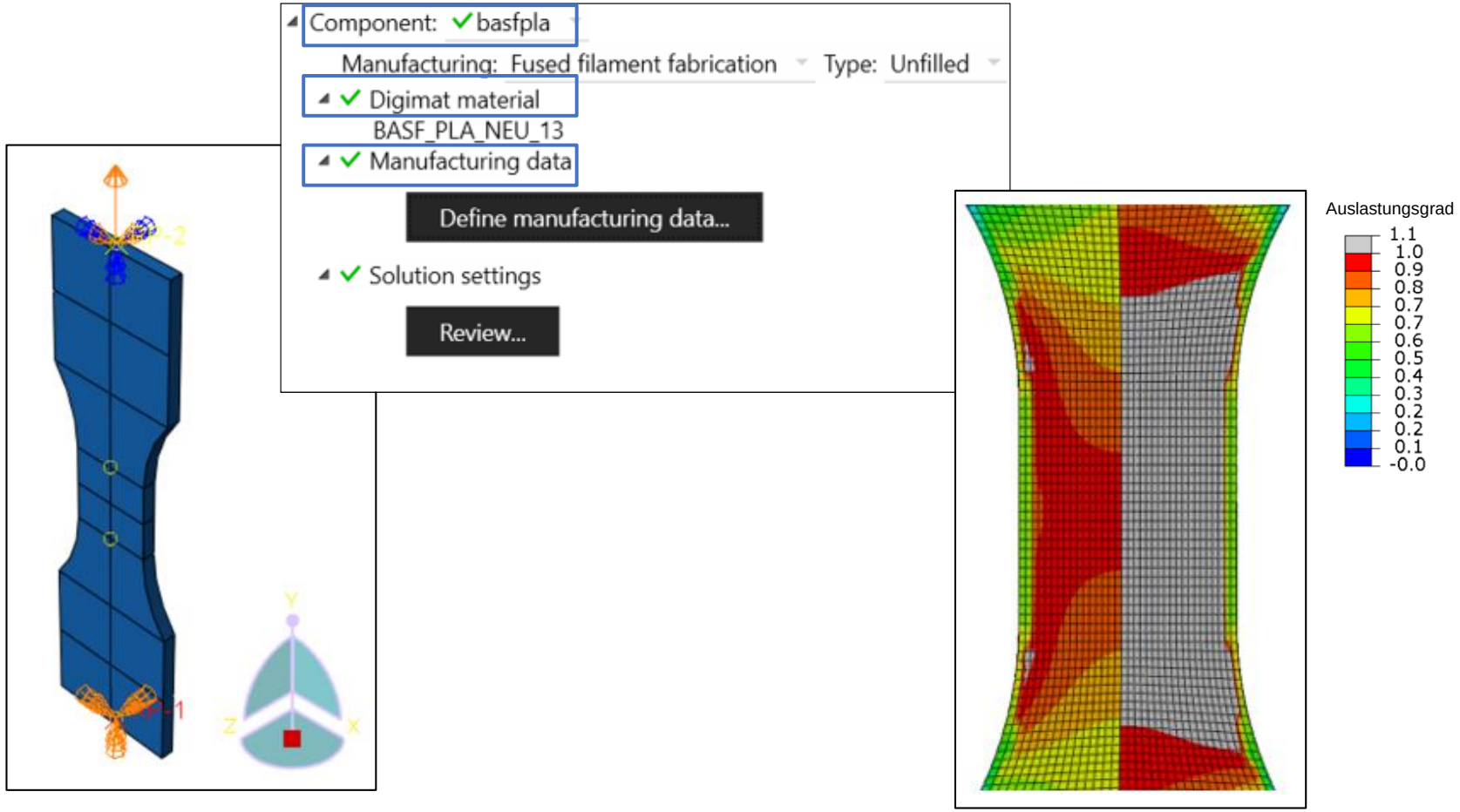


Kopplung des Strukturmodells

- Strukturmodell
- Materialverhalten
- Materialorientierung



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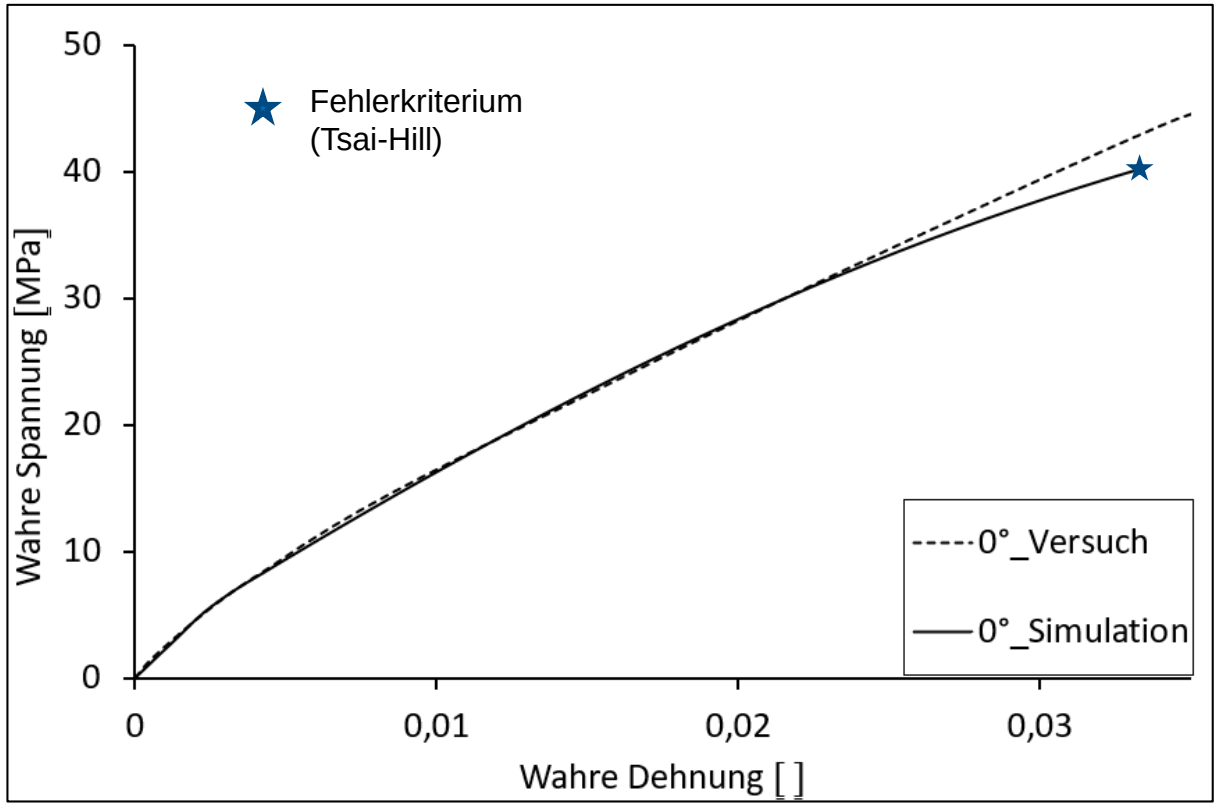
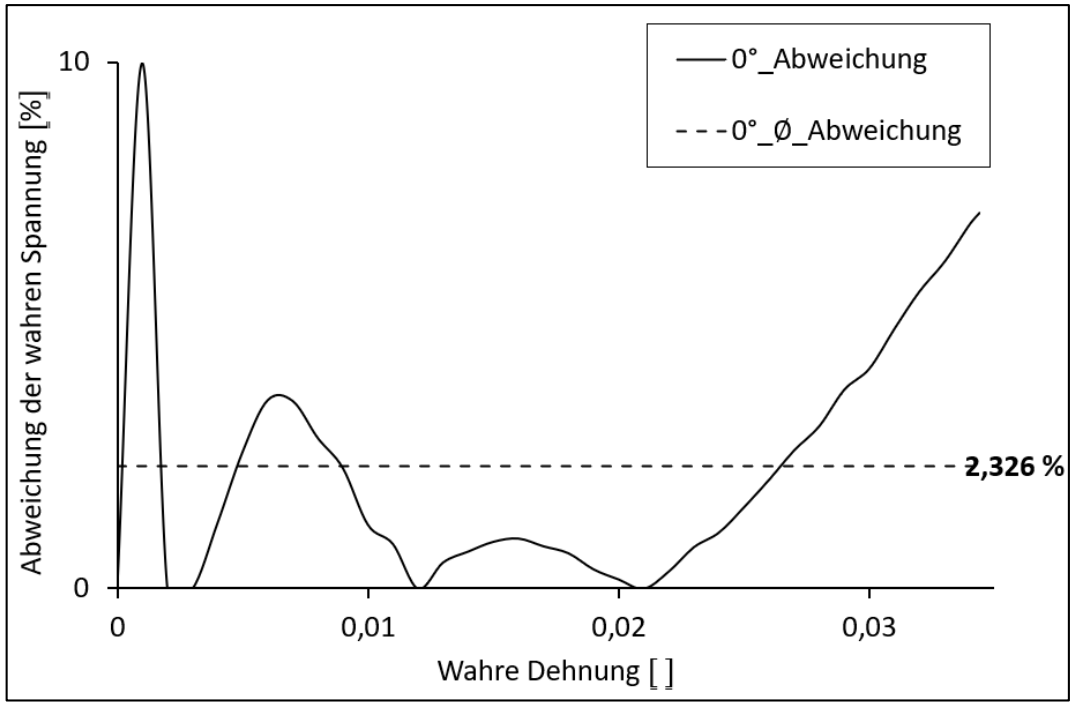
Gegenüberstellung von Simulations- und Versuchsergebnisse

Vergleich der wahren Spannungs-Dehnungskurven 0°

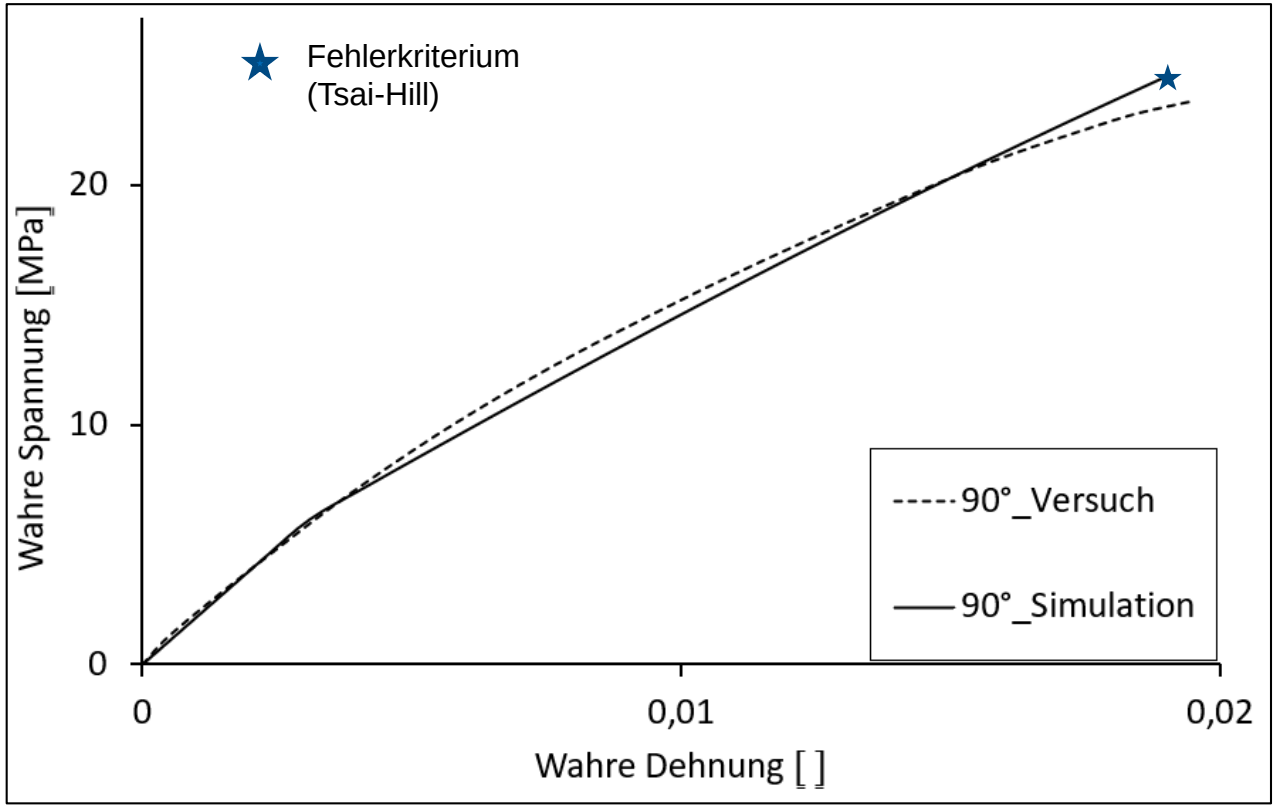


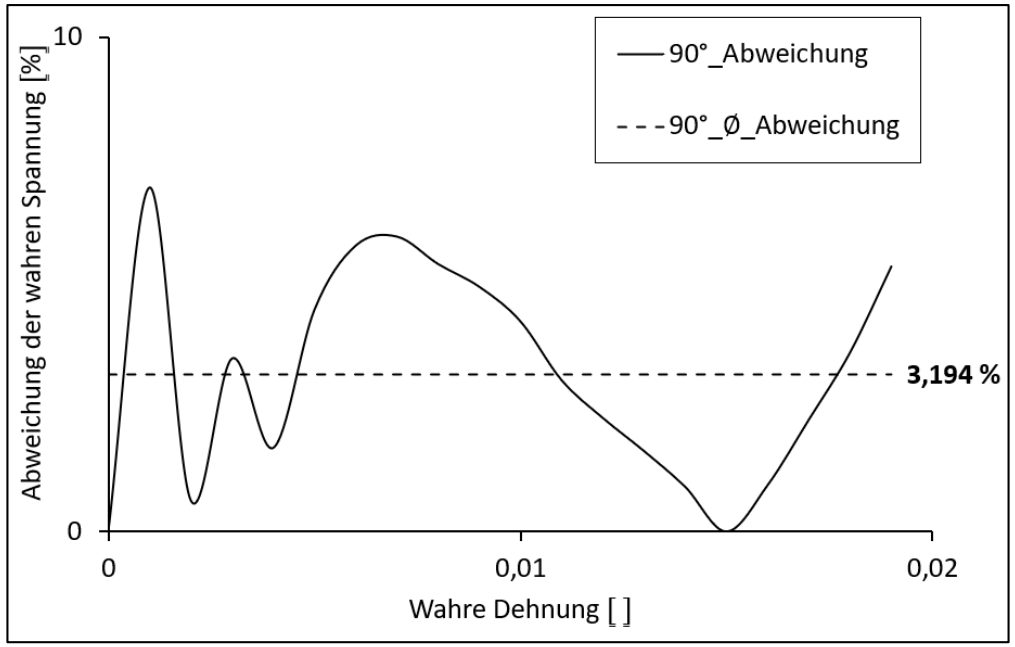


[G. A. Mazzei Capote, “Defining a failure surface for Fused Filament Fabrication parts using a novel failure criterion,” Sep. 2018]

Gegenüberstellung von Simulations- und Versuchsergebnisse

Vergleich der wahren Spannungs-Dehnungskurven 90°





[G. A. Mazzei Capote, “Defining a failure surface for Fused Filament Fabrication parts using a novel failure criterion,” Sep. 2018]

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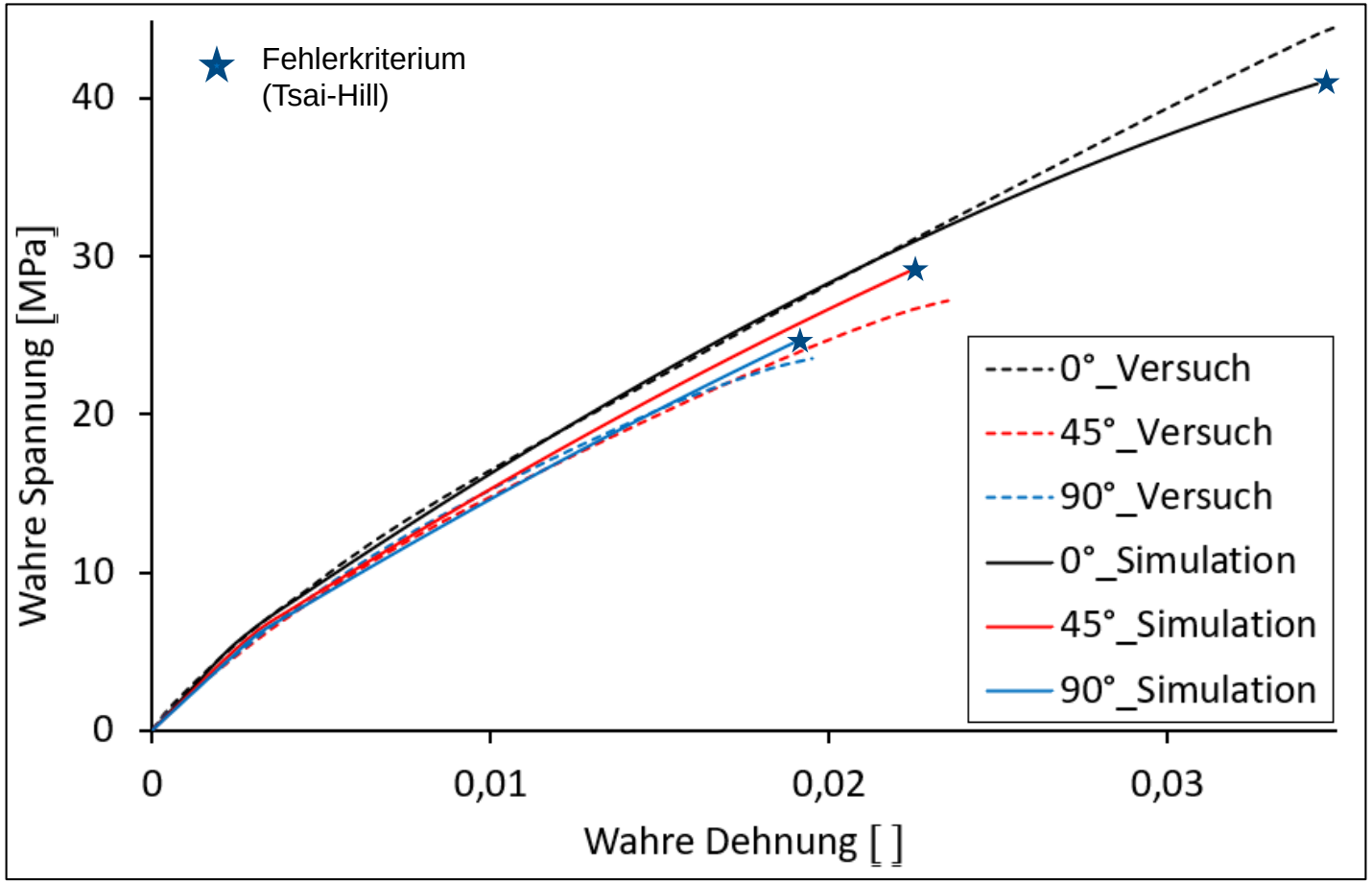
Gegenüberstellung von Simulations- und Versuchsergebnisse

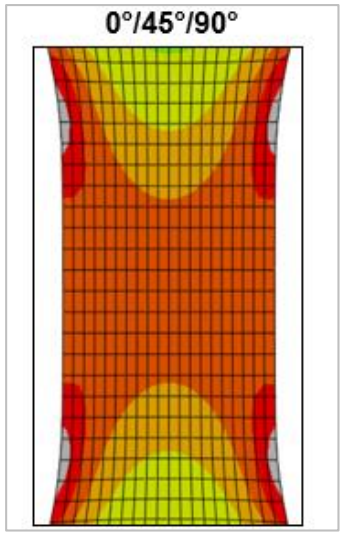
Gute Vorhersage der Richtungsabhängigkeit und des Versagens

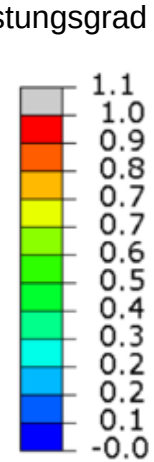


Gegenüberstellung: Lokales Versagen

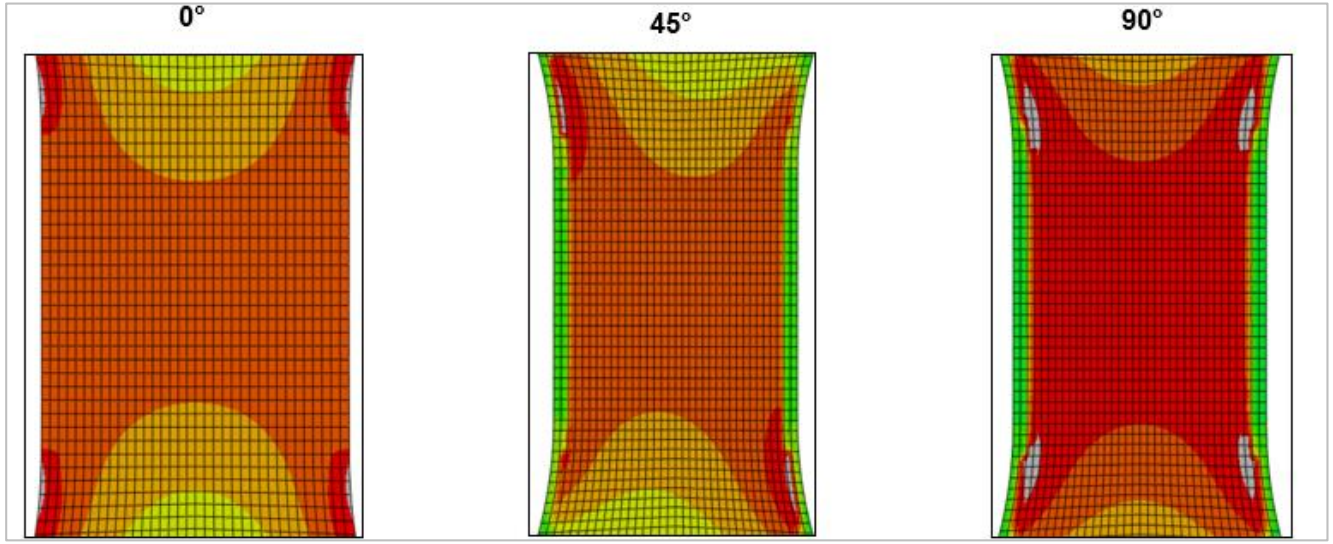
- Unterschied der Spannungsverteilung einer **isotropen** und einer **anisotropen** FEM Berechnung.

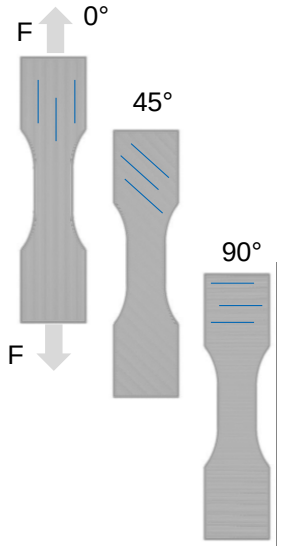
Isotrope
FEM Berechnung





Anisotrope
FEM Berechnung





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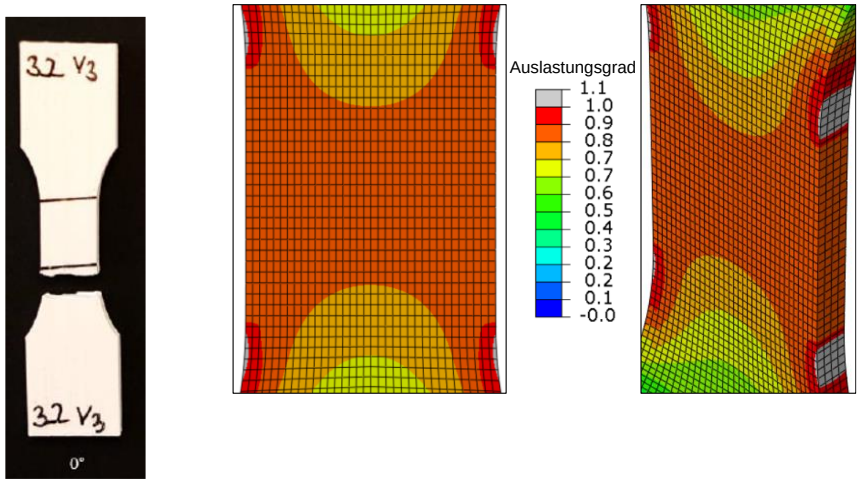
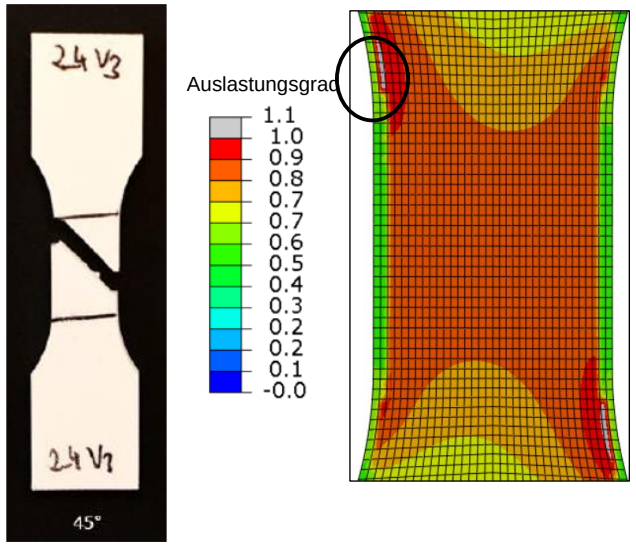
Gegenüberstellung: Lokales Versagen

Bruchverhalten 0°

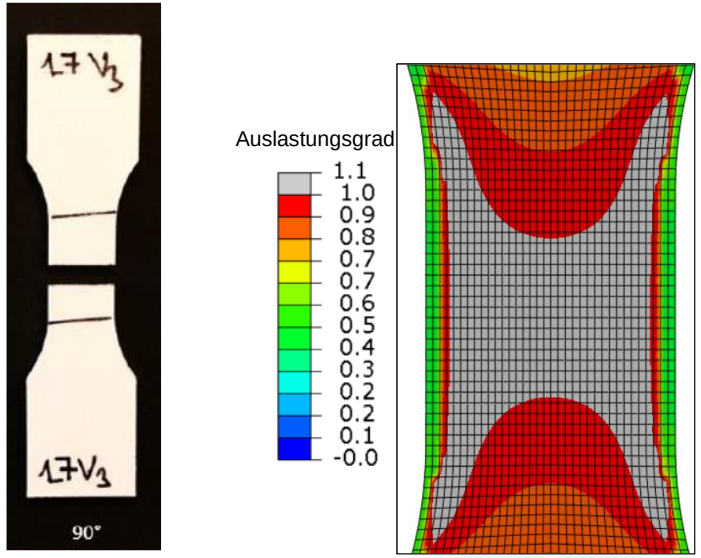
Lokales Versagen bei Auslastungsgrad > 1



Bruchverhalten 45°



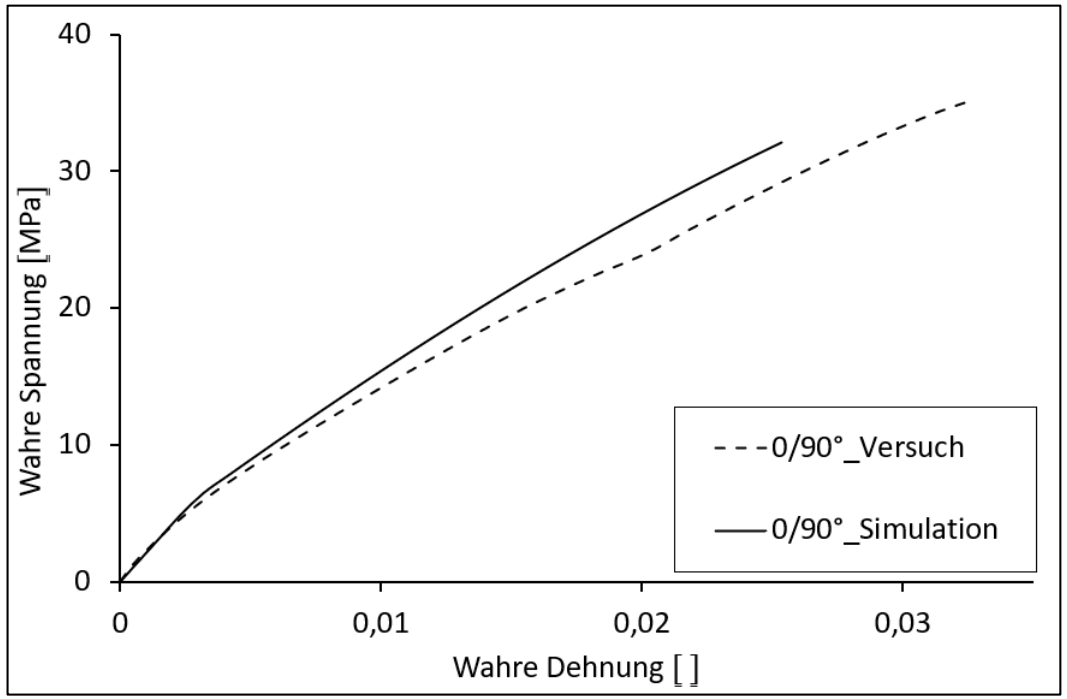
Bruchverhalten 90°



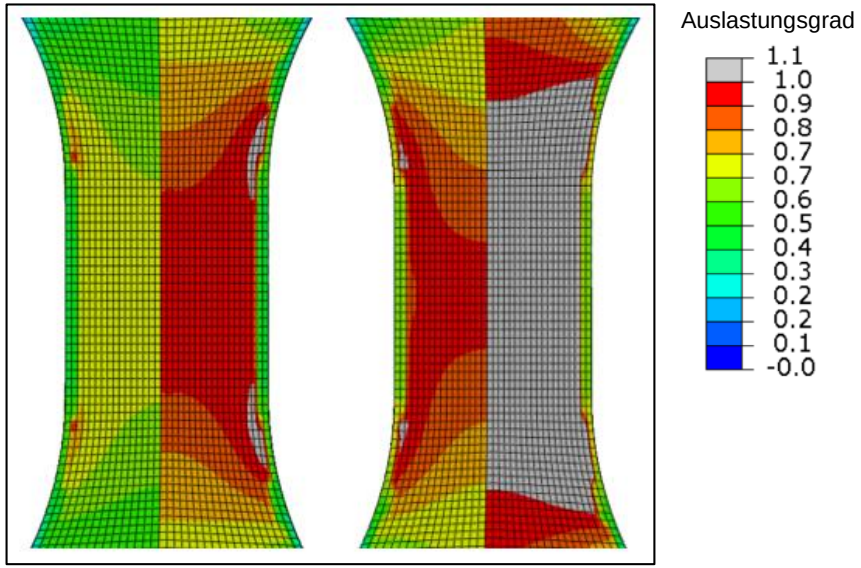
Hochschule Aalen

Simulationsergebnisse

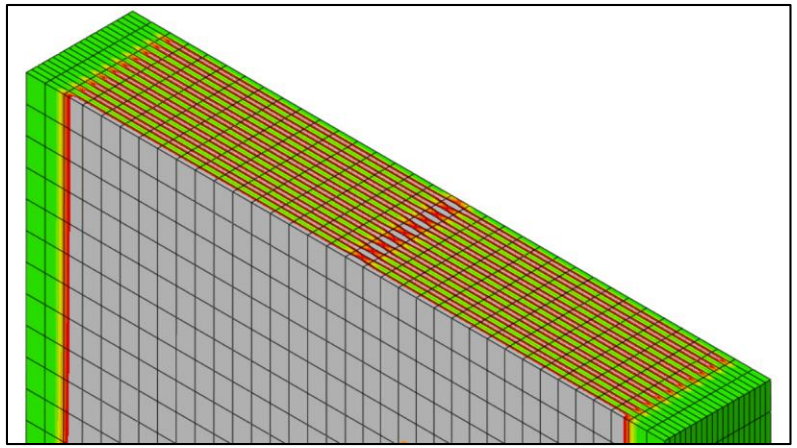
Kombination der Füllrichtung 0°/90°



Vergleich wahre Spannungs-Dehnungskurve 0°/90°



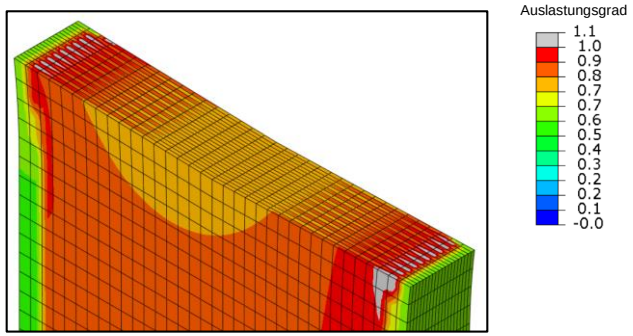
Versagen Schnittdarstellung 0°/90°



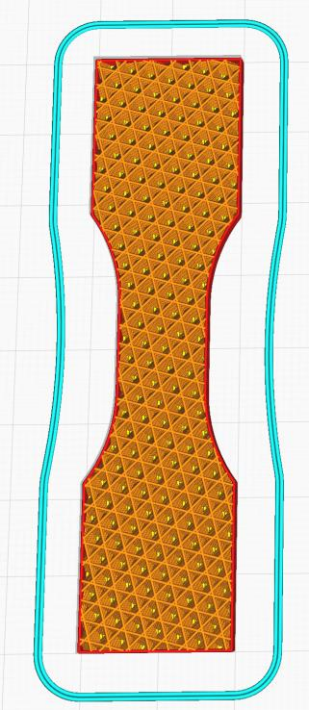
Versagen Schnittdarstellung 0°/90°

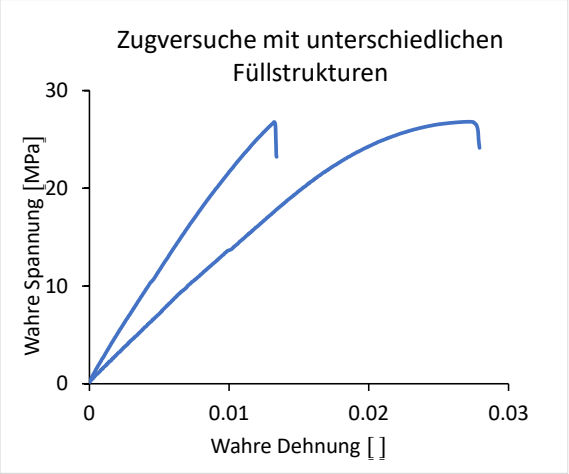
Fazit und Ausblick

- Gute Beschreibung des mechanischen Werkstoffverhaltens.



- Berücksichtigung des lokalen Deformationsverhaltens und des Versagens mittels Prozess - Struktur gekoppelter Simulation.





- Weiterentwicklung des Simulation zur Vorhersage des mechanischen Verhaltens für unterschiedlichen Füllgrade und Füllstrukturen.

Vielen Dank für Ihre Aufmerksamkeit