



Influence of creep load on the lifetime of short fiber reinforced polymers

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Content

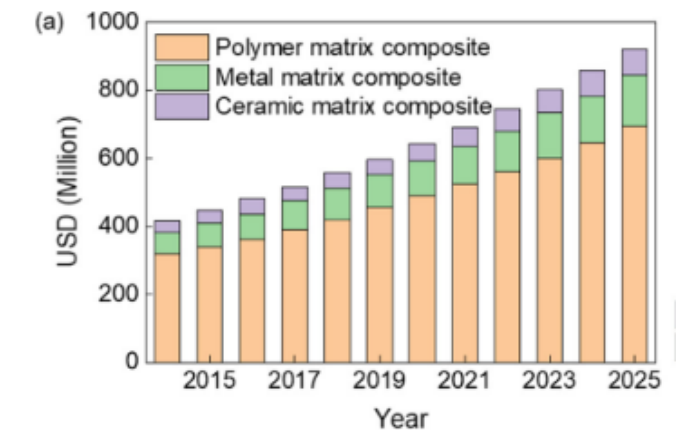
- **Introduction**
 - Motivation
 - Polymers
 - Polymers structural applications
 - Simulation chain
- **Methodical approach**
 - Materials and conditions
 - Test sequence
- **Results**
 - Comparison of polymer types
 - Influence of fiber orientation
 - Influence of static load level
 - Consideration in lifetime assessment
- **Conclusion and outlook**

Introduction

- **Motivation**
 - Lightweight applications
 - Reduction of CO₂ emissions/Electromobility
 - Substitution of metal components by polymers
 - Focus on thermoplastics
- **Specific load sequences**
 - Automotive rest most of their service lifetime
 - Cyclic loads
 - Material fatigue
 - Impact on the material behavior (strain rate dependency)
 - Static loads
 - Creep damage
 - Relaxation



Polymer components in a automobile [1]



The automotive polymer composite market revenue of the United State [2]

[1] Quitter, Dorothee (2010): Nachhaltige Kunststoffe fürs Auto. In: *Konstruktionspraxis*, 19.03.2010. Online verfügbar unter <https://www.konstruktionspraxis.vogel.de/nachhaltige-kunststoffe-fuers-auto-a-256055/>, zuletzt geprüft am 21.09.2021.918Z.

[2] Zhang, Wen; Xu, Jun (2022): Advanced lightweight materials for Automobiles: A review. In: *Materials & Design* 221, S. 110994. DOI: 10.1016/j.matdes.2022.110994

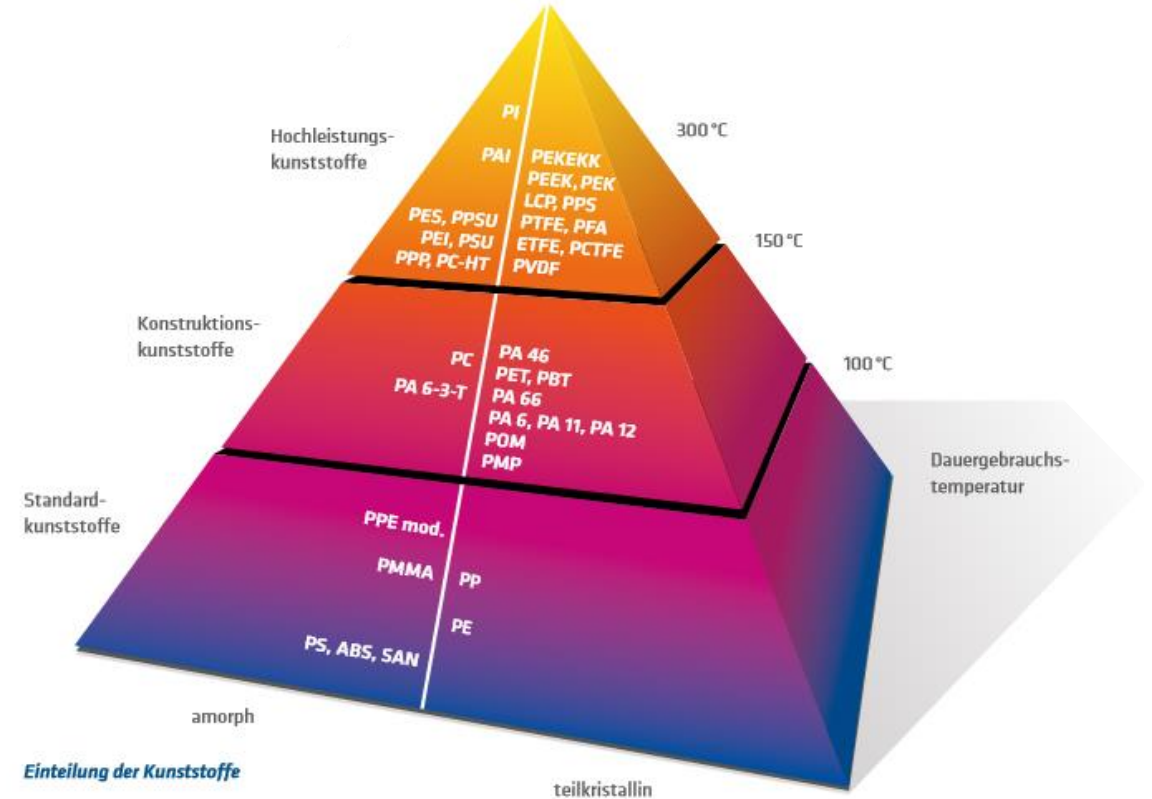
Introduction

- **Polymers**

- Mainly distinguished between:
 - Thermoplastics
 - Thermosets
 - Elastomers
- Way different (and influenceable) properties and areas of operation
- Time dependent behavior
- Reinforced by fibers → Anisotropic behavior

- **Polymers in structural applications**

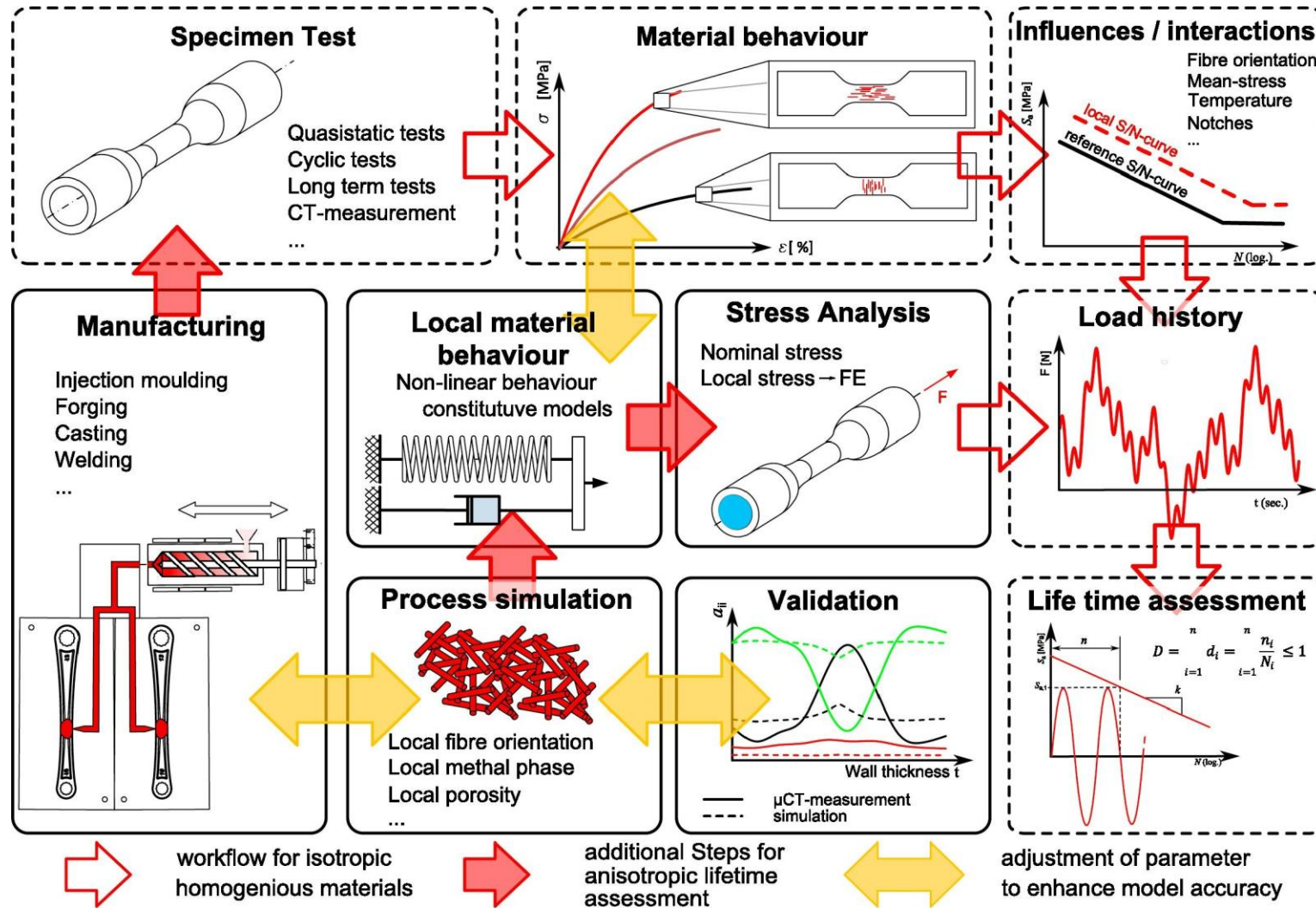
- Main advantage is the enormous lightweight potential
- Complex forms are easily possible
- Cost effective components



Division of polymers depending on the temperature of usage [3]

[3] Ensinger. In: *Technische Kunststoffe – Das Handbuch*, Online verfügbar unter <https://docplayer.org/1260510-Halbzeuge-technische-kunststoffe-das-handbuch.html>, zuletzt geprüft am 21.09.2021.918Z.

Introduction



Simulation chain for lifetime assessment of short fiber reinforced polymers according to [4]

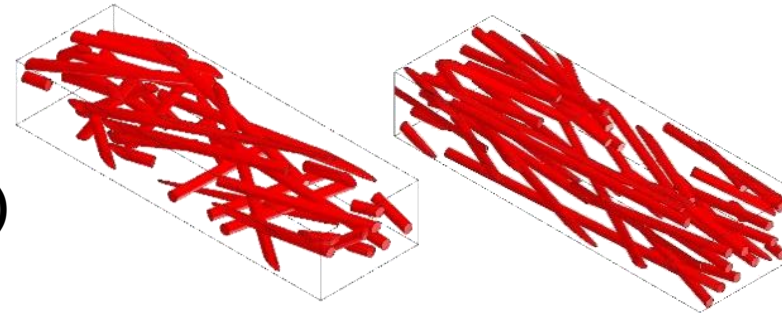
[4] Pimetzhofer, Andreas; Stadler, Gabriel; Pinter, Gerald; Grün, Florian (2018): Lifetime assessment of anisotropic materials by the example short fibre reinforced plastic. In: International Journal of Fatigue. DOI: 10.1016/j.ijfatigue.2018.06.013

Content

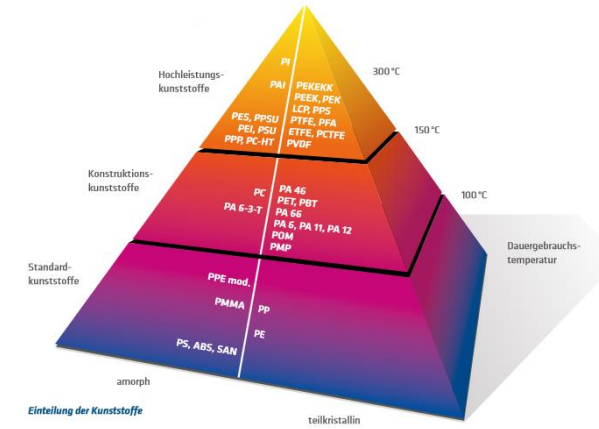
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Methodical approach

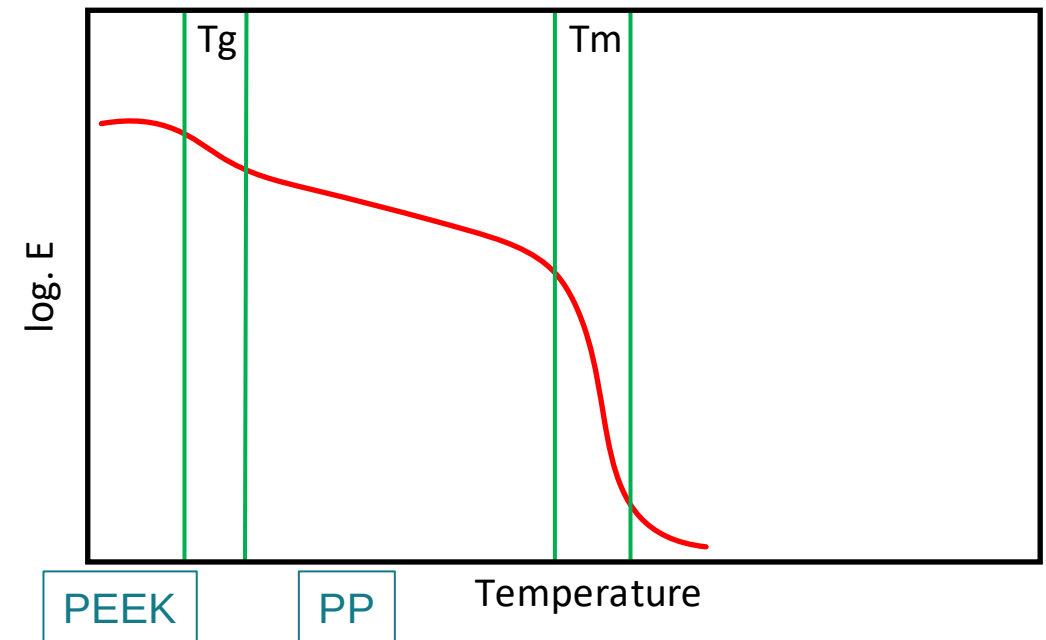
- **Materials**
 - PP GF 40
 - PEEK GF 14
- **Conditions (depending on the polymer)**
 - Beneath glass transition temperature (T_g)
 - Low to zero polymer chain movements
 - Brittle
 - Above T_g
 - Increased polymer chain movement
 - Ductile
- **Fiber orientations**
 - Influences (fatigue) strength
 - Time depended material behavior



Schematic picture of random and directed fibers



Division of polymers according to [2]



Schematic stiffness route of thermoplastic polymers according to [6]

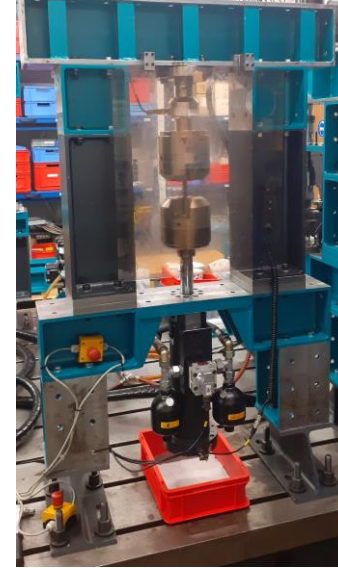
[2] Ensinger. In: Technische Kunststoffe – Das Handbuch, Online verfügbar unter <https://docplayer.org/1260510-Halbzeuge-technische-kunststoffe-das-handbuch.html>

[6] Grellmann, Wolfgang; Seidler, Sabine (2011): Kunststoffprüfung. 2. Aufl. München: Hanser

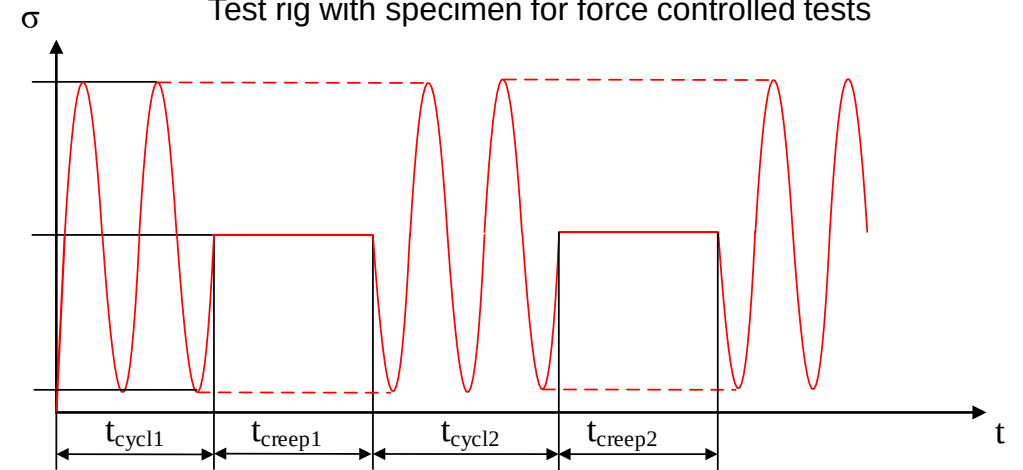
Methodical approach

- **Tests**

- Cyclic tests for fatigue behavior and lifetime
 - $R=-1$; $R=0.1$, $R=0.5$, $R=0.8$
 - $T=RT$
 - Short specimen
 - Rotating bending specimen
- Combined tests
 - Load shares: cyclic/static load 50%/50%
 - Different static load levels: Min., mean, max. load
 - $T=RT$
- Static tests for creep rupture
 - $T=RT$
 - $R=1$



Test rig with specimen for force controlled tests



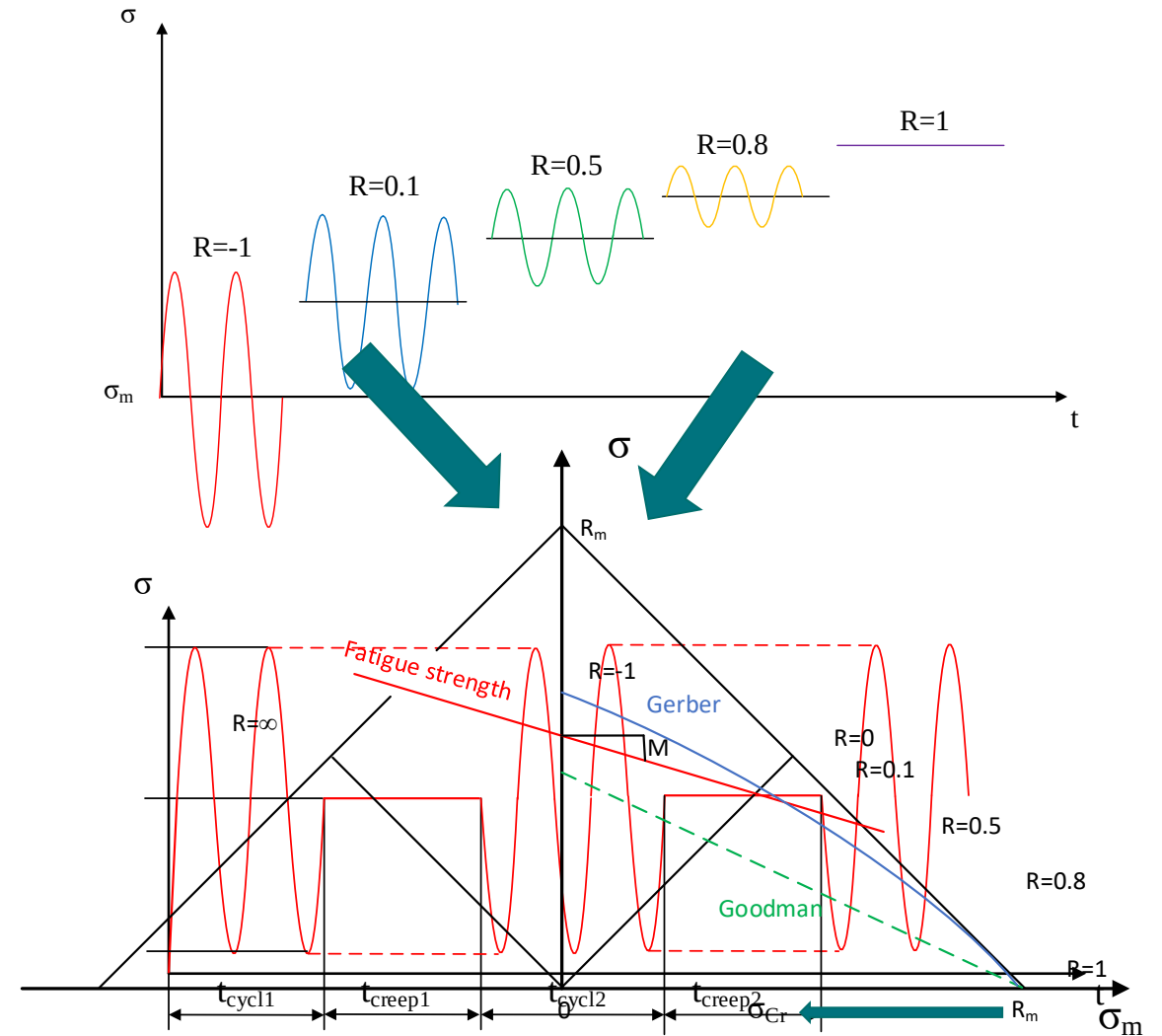
Schematic picture of the load sequence according to [7]

[7] Stadler, Gabriel; Primetzhofer, Andreas; Jerabek, Michael; Pinter, Gerald; Grün, Florian (2020a): Investigation of the Influence of Viscoelastic Behaviour on the Lifetime of Short Fibre Reinforced Polymers. In: *Polymers* 12 (12). DOI: 10.3390/polym12122874

Methodical approach

- **Influence factors**
- **Mean stress**
 - Increasing mean stress
 - Decreased stress amplitude
 - Cyclic creep
 - Limit by $R=1 \rightarrow$ **Creep rupture strength**
- **Constant load share**
 - Increased constant load share
 - Limit: **Creep rupture strength**
- **Mean stress sensitivity depending on**
 - Material
 - Constant loads

[8] Stadler, Gabriel (2021): Berücksichtigung der Viskoelastizität in der Betriebsfestigkeitsanalyse von kurzfaserverstärkten Kunststoffen. Dissertation. Montanuniversität Leoben, Leoben.



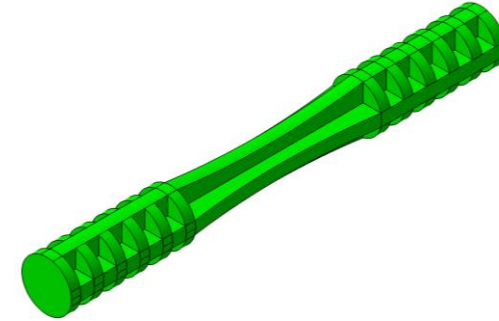
Schematic Haigh diagram including mean stress models and load sequences [8]

Methodical approach

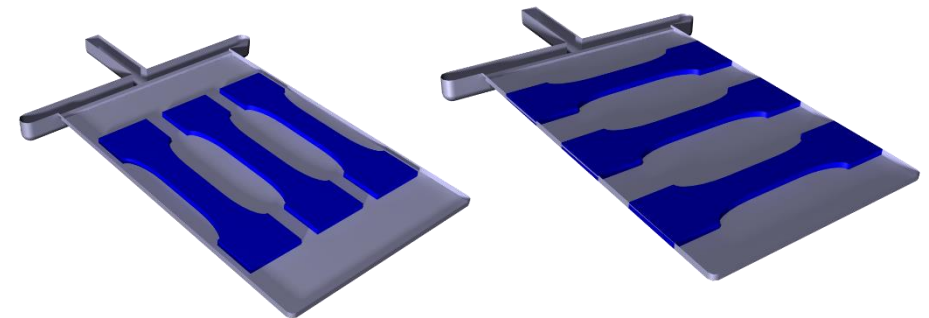
- **Specimens**

- Rotating bending specimen
 - Manufactured directly
 - Main fiber orientation longitudinal
- Short specimen
 - Basis: Plate
 - Extracted by milling
 - Different fiber orientations
 - Mainly longitudinal
 - Mainly transversal

- **Production: Injection molding**



Injection molded specimen according to [4]



Extraction positions of the short specimens [1]

[4] Mösenbacher, A.; Guster, Christoph (2012): Fatigue behaviour of a short glass fibre reinforced polyamide. Effect of notches and temperature. In: Chair of Mechanical Engineering (Hg.): 3rd Fatigue Symposium Leoben. 3rd Fatigue Symposium Leoben, Lightweight Design. Leoben, Austria. Leoben: Chair of Mechanical Engineering, S. 152–160.

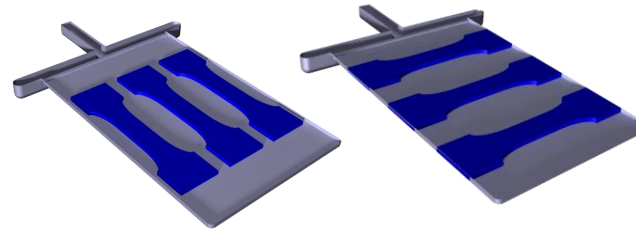
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Results

- **Pure cyclic tests (reference)**

- Reference stress ratio: $R=-1$
- Reference bearable number of cycles: $N=10^6$

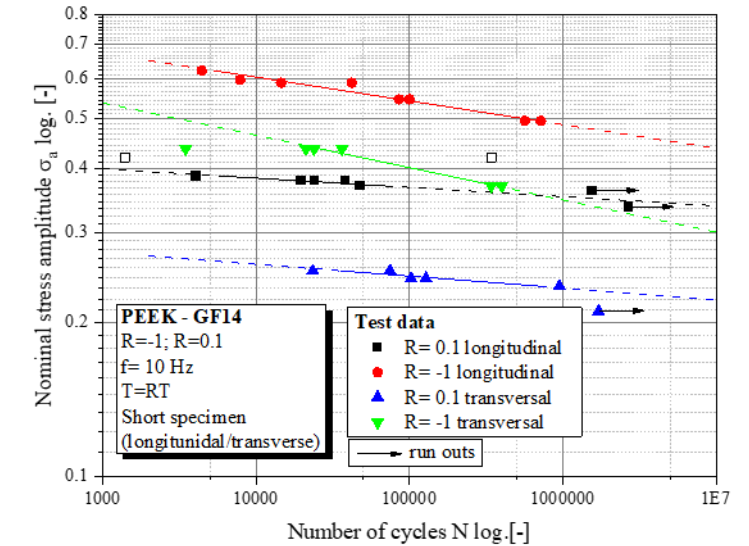
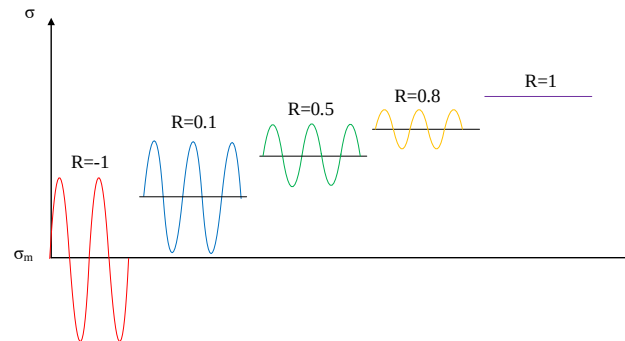


- **Mean stress sensitivity**

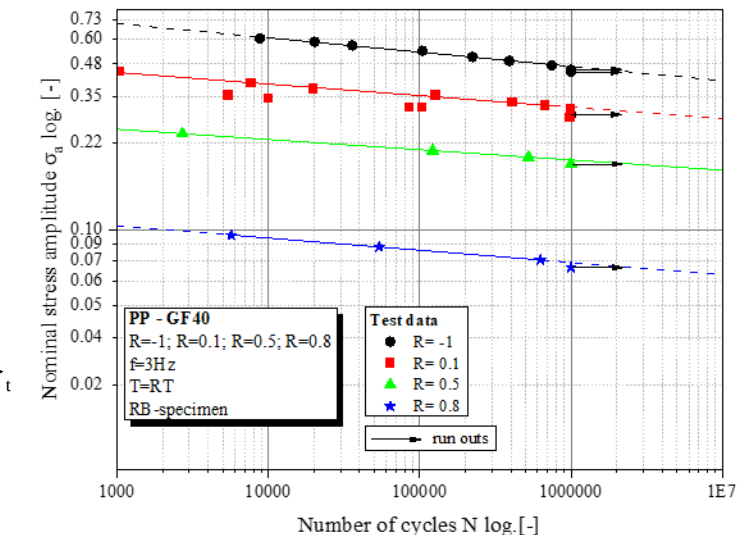
- Difference of bearable stress amplitude between investigated stress ratios approx. 85%
- Stress amplitude difference decreases with increasing R-ratio

- **Influence of fiber orientation**

- Difference of approx. 29% for $R=-1$ and 32% for $R=0.1$ depending on the fiber orientation



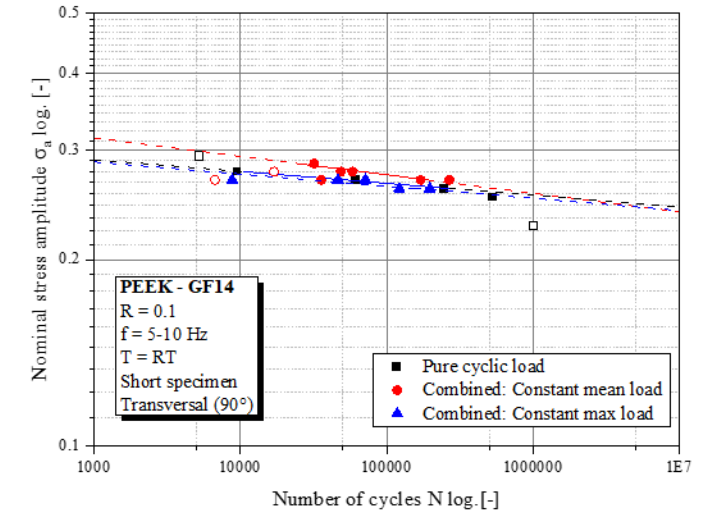
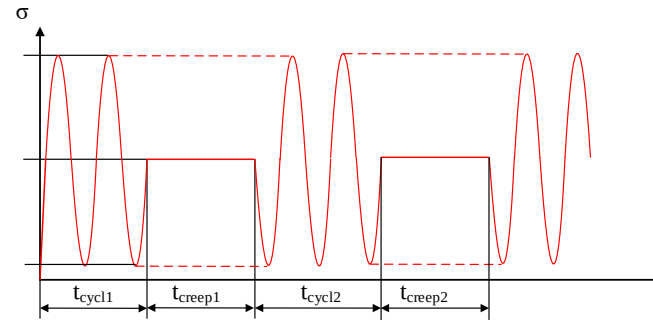
Results of pure cyclic test for the fiber orientation influence on PEEK GF-14



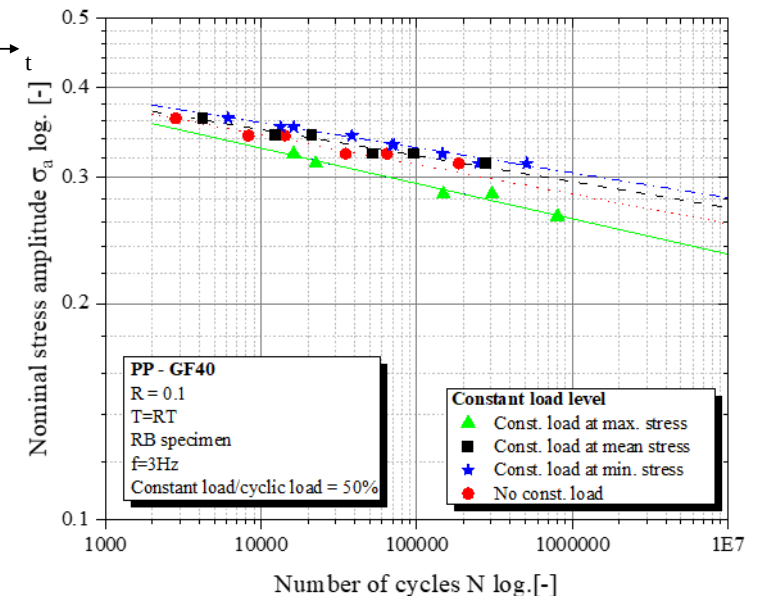
Results of pure cyclic test for mean stress influence on PP – GF40

Results

- **Comparison of polymer types**
 - PP
 - PEEK
- **Influence of static loads**
 - Fiber orientation longitudinal of PEEK specimen comparable to rotating bending specimen of PP
 - Strength drop of 4% for PP and constant mean stress compared to pure fatigue load
 - Strength drop of 1.4% for PEEK transverse
- **Creep influence matrix dominated**
- **Fiber content neglectable for the investigated cases**



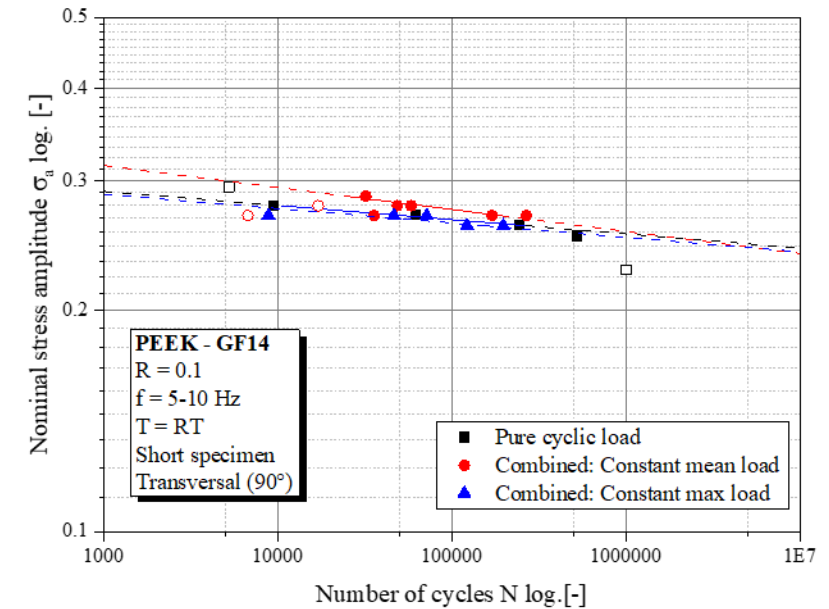
Results of combined cyclic/creep tests on PEEK GF-14



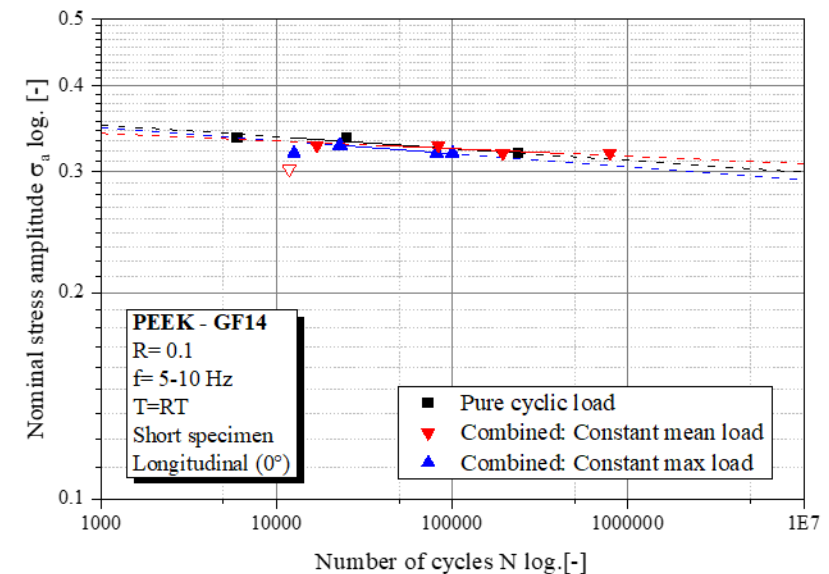
Results of combined cyclic/creep tests on PP GF-40 according to [7]

Results

- **Influence of fiber orientation**
 - Longitudinal
 - Transversal
- **More pronounced effect with transversal oriented fibers**
- **Influence of load level on lifetime**
 - Decrease with constant load maximum load level
 - Increase with constant load mean load level
- **Matrix dominated**



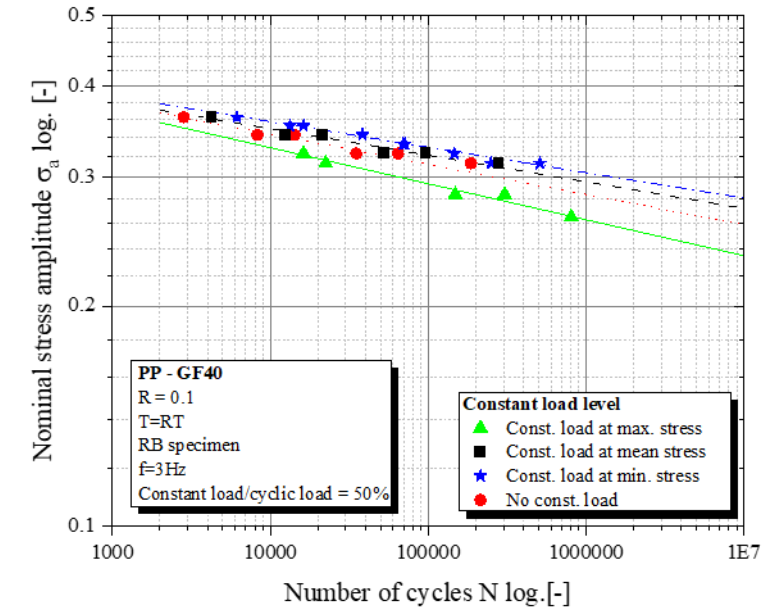
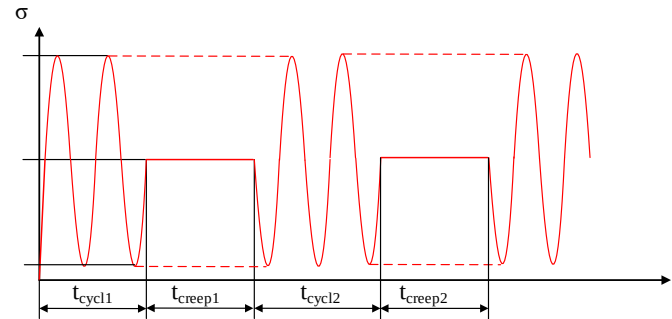
Results of combined cyclic/creep tests on PEEK GF-14 (transverse)



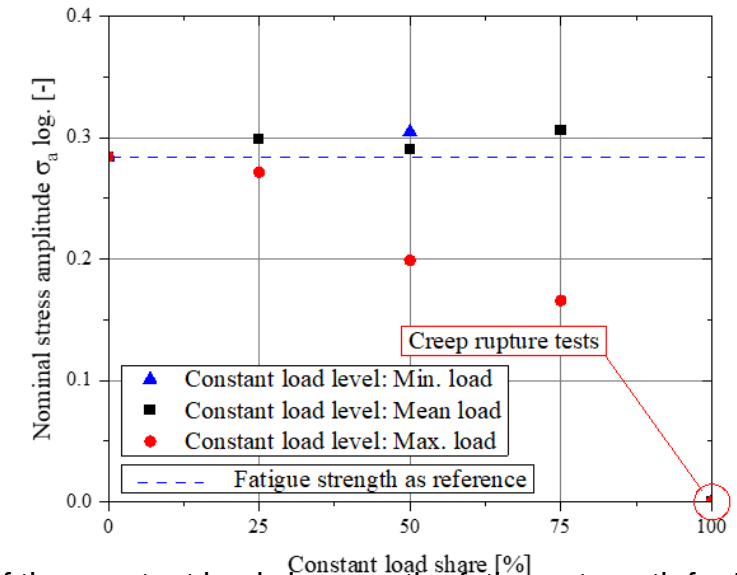
Results of combined cyclic/creep tests on PEEK GF-14 (longitudinal)

Results

- **Influence of constant load level**
- **Three constant load levels**
 - Minimum stress
 - Mean stress
 - Maximum stress
- **Lifetime increase or decrease**
 - Min load increase
 - Mean load increase
 - Max load decrease
- **Relaxation between cyclic loading**
- **Creep damage between cyclic loads**



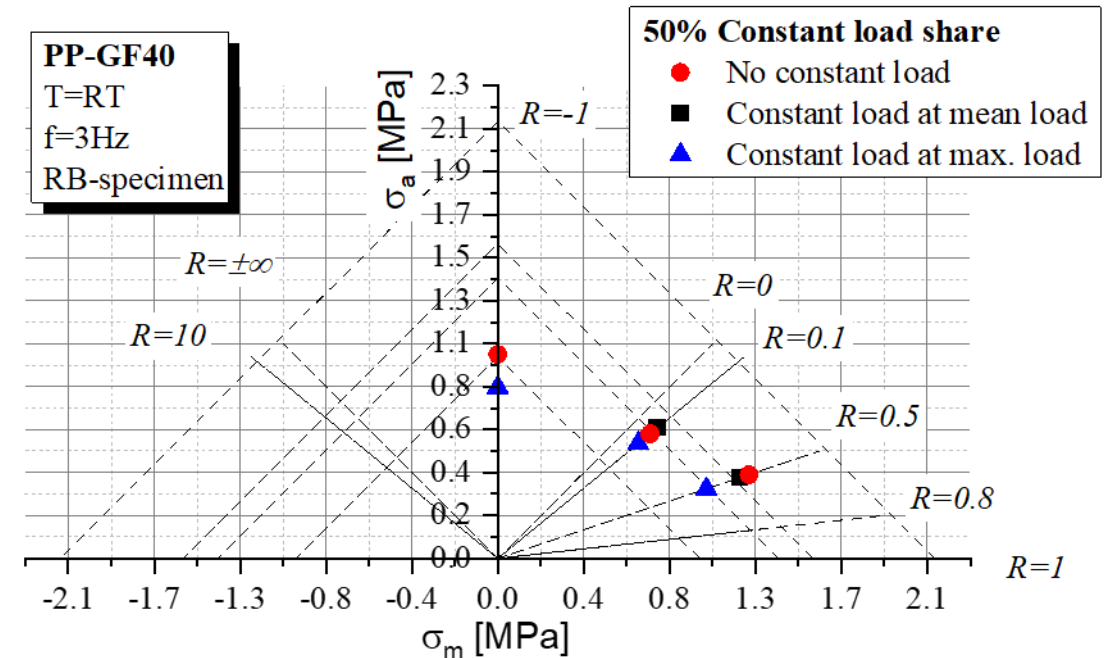
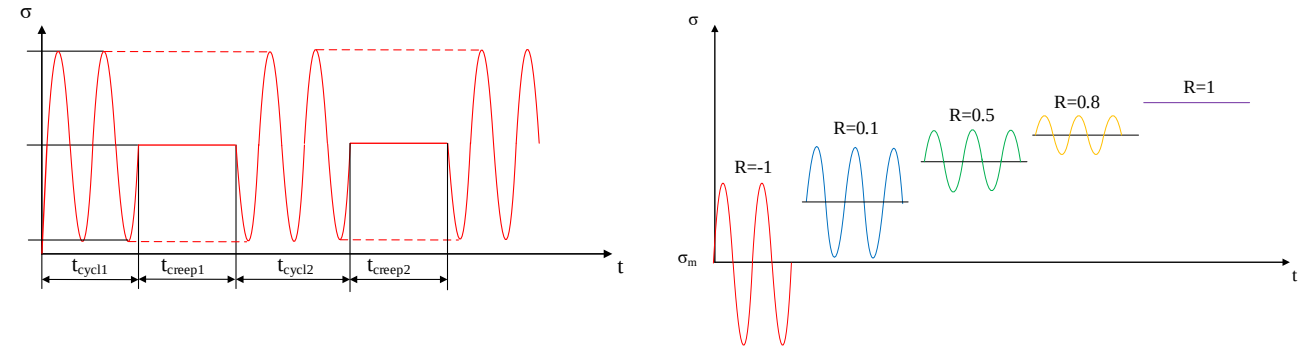
Influence of the constant load level on the S/N curves for PP-GF40 [7]



Influence of the constant load share on the fatigue strength for PP-GF40 [8]

Results

- **Influence on mean stress sensitivity**
 - Depends on the constant load level
 - Mean stress sensitivity drops with constant loads
- **Limit: Creep rupture strength**
- **Isochronic Haigh diagram**
 - Captures static load shares
 - Delivers the creep rupture limit for a certain load duration (e.g. years)



Effect of constant loads on the resulting Haigh diagram for PP-GF40 [8]

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Conclusion and outlook

- **Conclusion**

- Combined tests to capture “service life load conditions” have been performed
- Constant loads influences the lifetime
- This effect depends on the polymer
- The limitation is the creep rupture strength
- Combined loads influences the mean stress sensitivity
- **Important to consider constant loads in lifetime estimation**

- **Outlook**

- Further tests with different constant load shares needed to be investigated
- The method needed to be used for further polymers

Acknowledgement

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Tank you for your attention!