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UNIVERSITÄT
ERLANGEN-NÜRNBERG
TECHNISCHE FAKULTÄT

Chair of
Engineering Design
Friedrich-Alexander-University Erlangen-Nuremberg
Prof. Dr.-Ing. Sandro Wartzack

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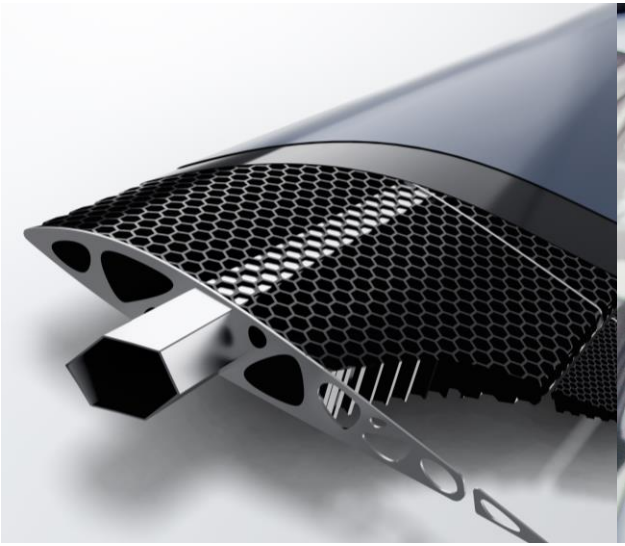
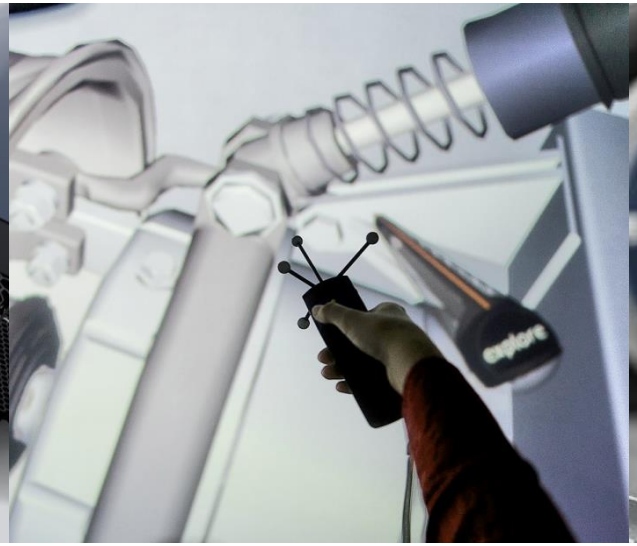
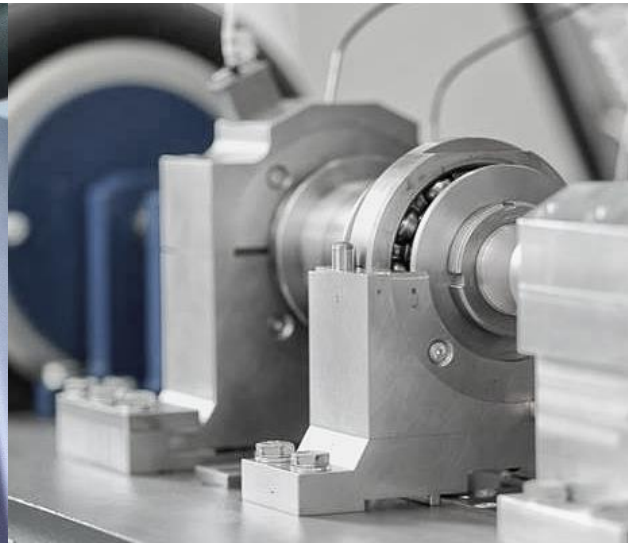
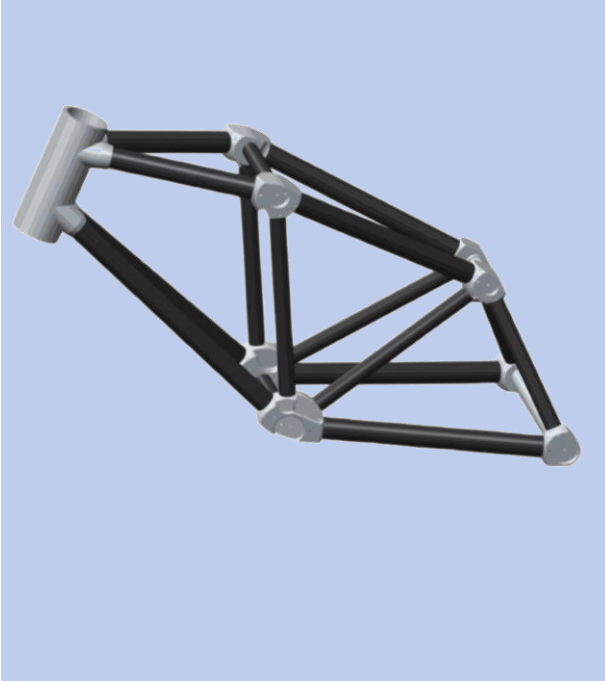
Modular Multi-Material Truss Structures – Design Space Optimization and experimental Validation

Michael Jäger, Prof. Dr.-Ing. Sandro Wartzack

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

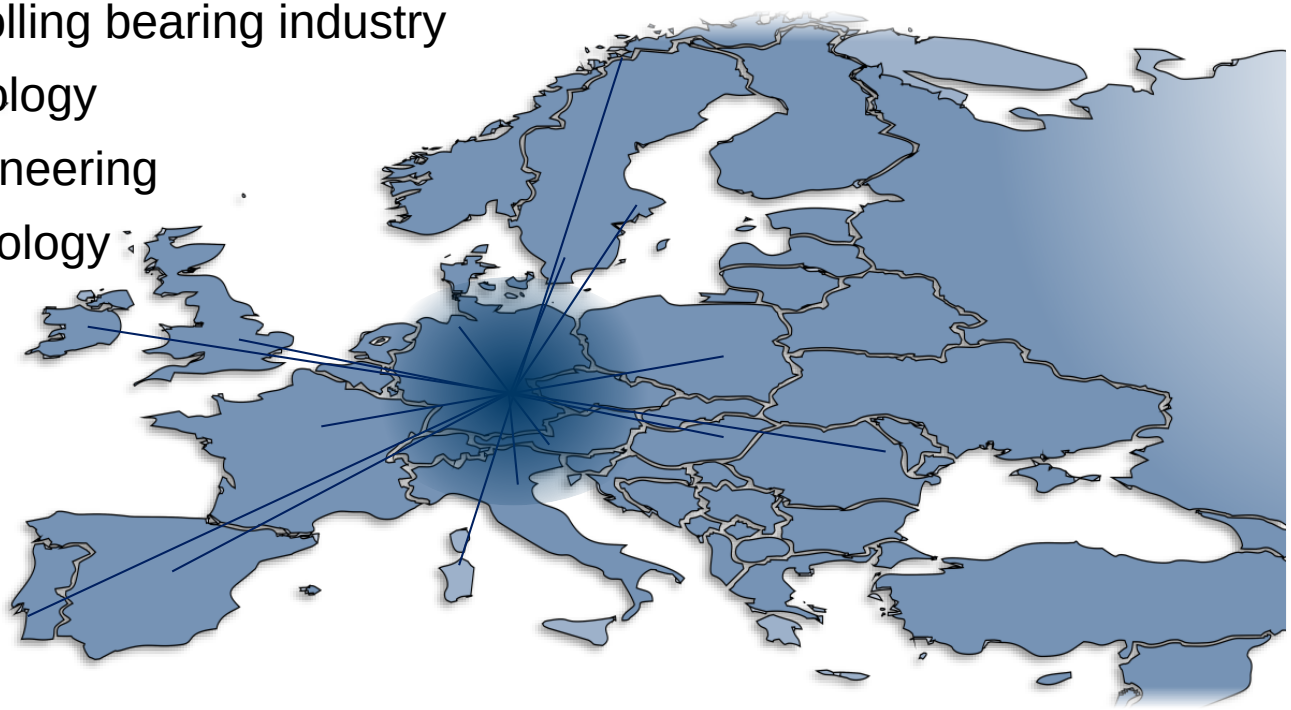
Outline



- Introduction
- CAE-based design method
- Validation
- Testing Equipment
- Summary

Engineering Design
Our location

- …in the centre of the metropolitan region of Nuremberg
- …in one of the heaviest industrialized regions of Germany
- …in one of the most innovative regions of Germany
- Focuses:
  - Automotive
  - Mechanical engineering
  - Heart of the rolling bearing industry
  - Energy technology
  - Electrical engineering
  - Medical technology

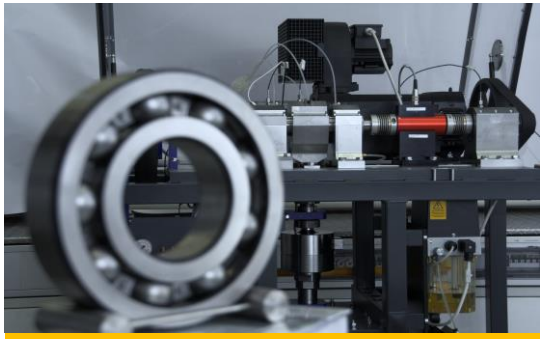


Engineering Design

Organisation structure and research groups

Virtual product development and engineering methodology

- Digital Engineering
- Dimensional Management
- User-centred design



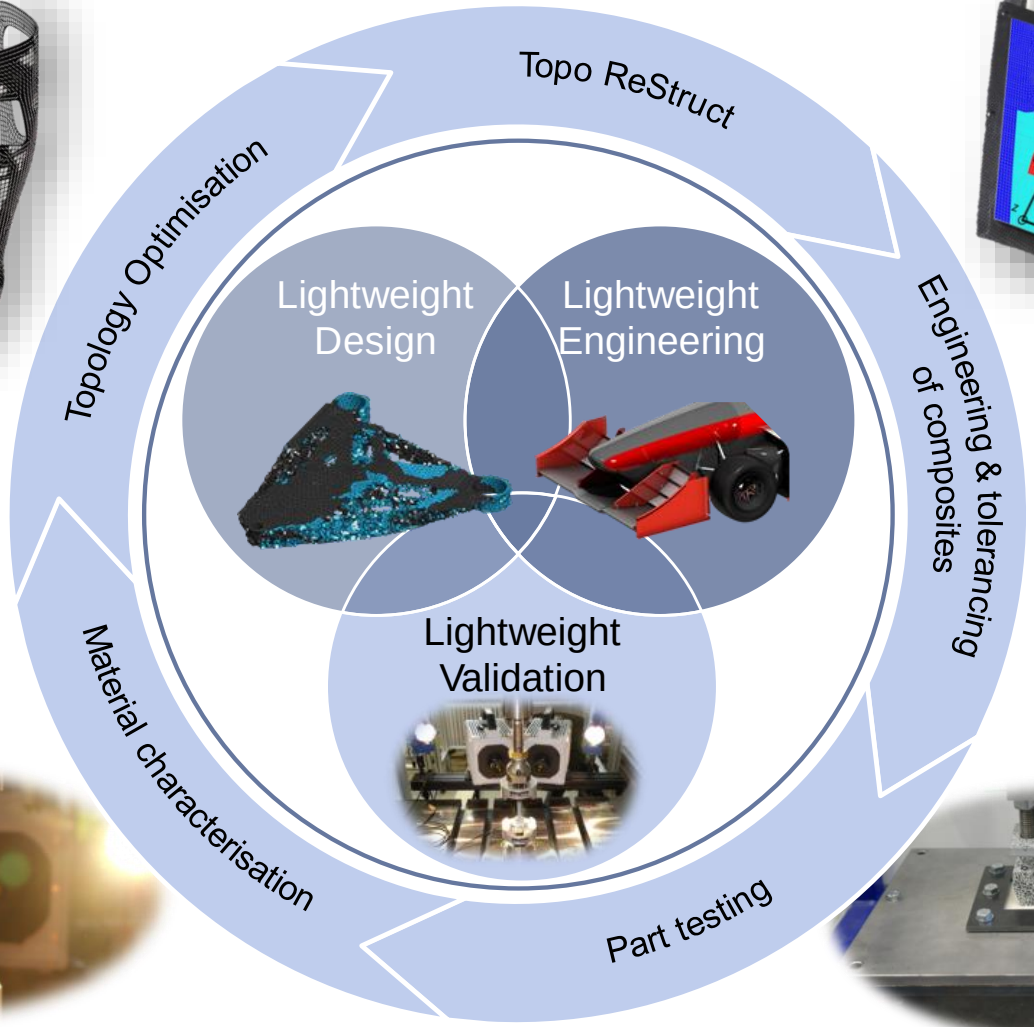
Machine elements and component design

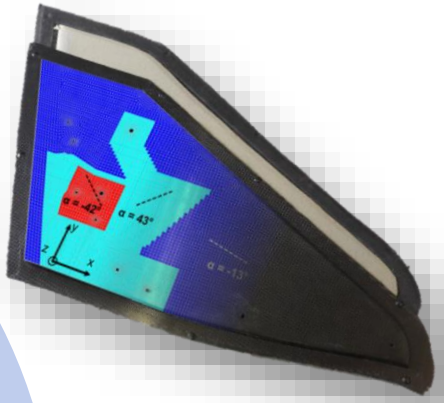
- Tribological PVD / PACVD coating systems
- Rolling bearing technology

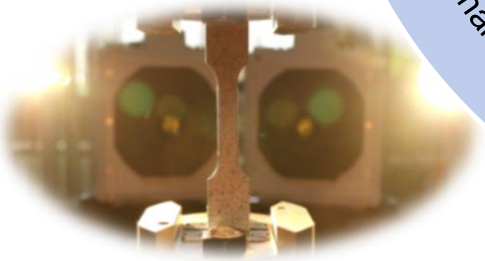
Lightweight Design

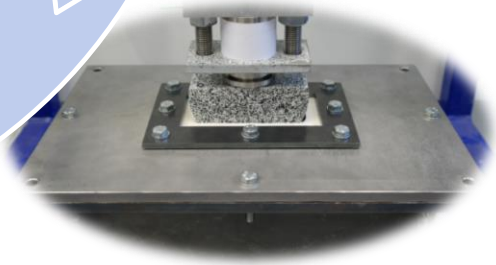
- Lightweight-Design
- Lightweight-Engineering
- Lightweight-Validation

Engineering Design
Lightweight Design









Introduction
Multi-Material Structures

Gefördert durch:
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Composites have highly anisotropic properties

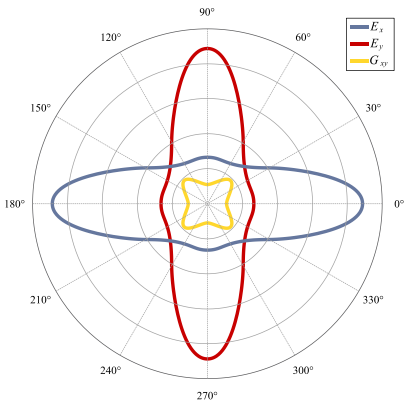
Utilization of stiffness/strength by opting for uniaxial stress

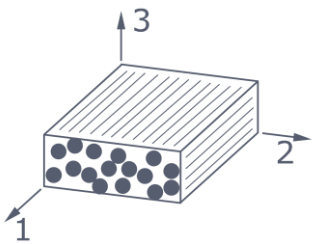
Truss Structures

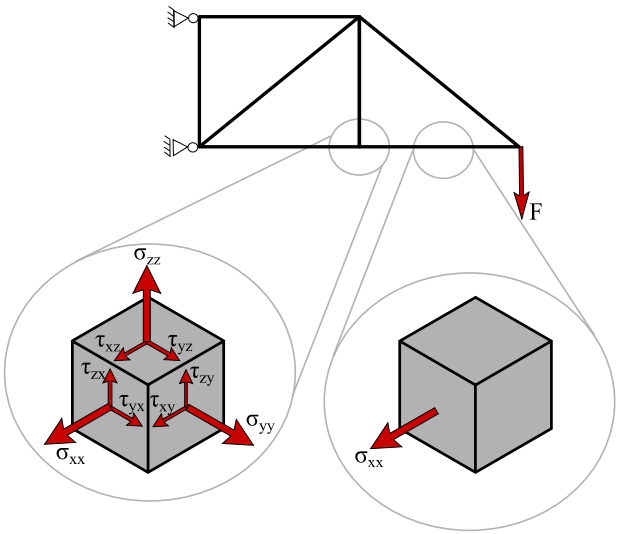
- **Uniaxial** stress state in struts
- **Multi**-axial stress state in nodes

Multi-Material Structures

- Composite struts
- Metal nodes







Introduction
Modular System

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Hand laminated

Modular system

Picture source: pasculli.de

Introduction
Standardization

Gefördert durch:
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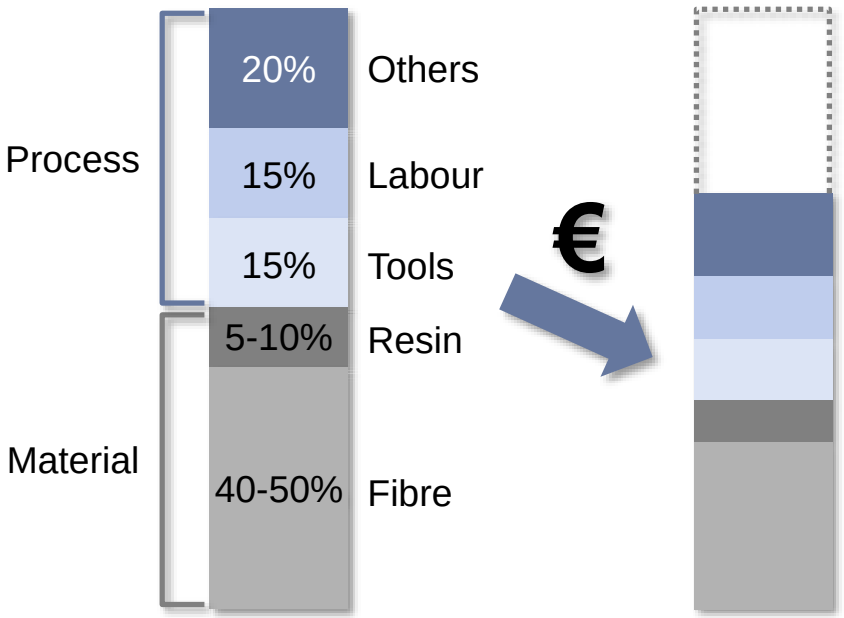
Fibre-reinforced composites have excellent mechanical properties

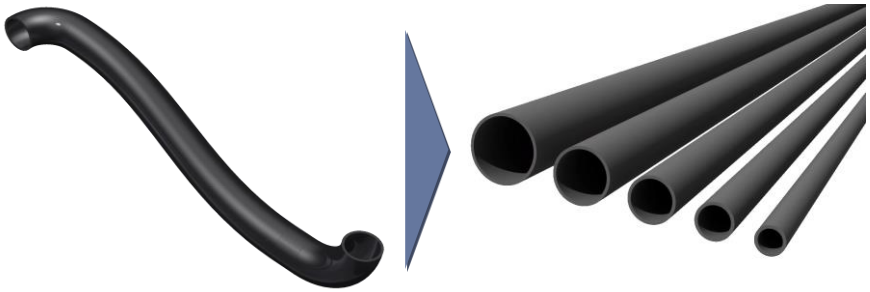
- high stiffness
- high strength
- low density

- high material cost
- high production cost



Reduction of costs by standardization

- Standardization of components
- Standardization of development



Eickenbusch, Heinz; Krauss, Oliver (2013): Kohlenstofffaserverstärkte Kunststoffe im Fahrzeugbau –Ressourceneffizienz und Technologien. Kurzanalyse Nr. 3 und Dokumentation des Fachgesprächs. VDI Zentrum Ressourceneffizienz GmbH. Berlin.

Design Process

Overview

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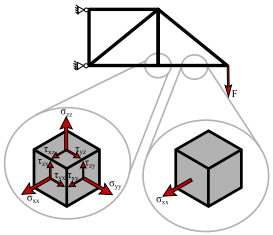


Multi-Material

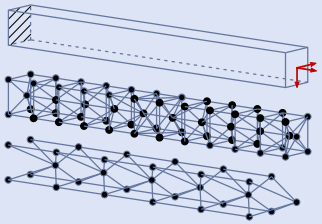
Modular

Standardized

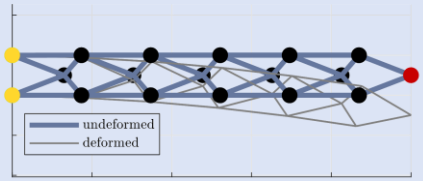
Automated Design Process

Requirements

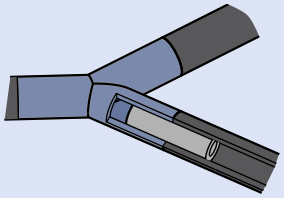
Topology Optimization



Discrete Optimization



CAD-Model Generation



System Design

Design Process
Topology Optimization

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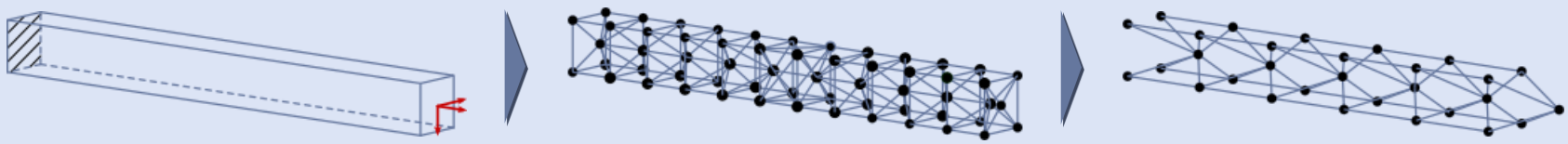
Topology Optimization

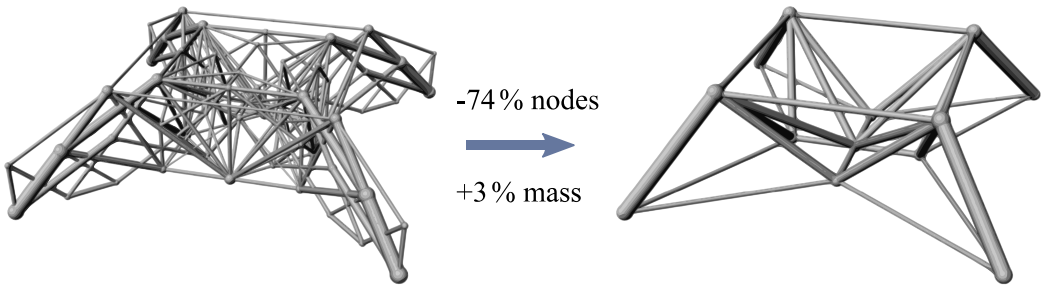


Mass Minimization

Optimization Constraints
- Node displacement
- Permissible stresses

Manufacturing Constraints
- Angle between struts
- Number of struts

limitstate form



Fairclough et al. (2018)

Design Process

Discrete Optimization

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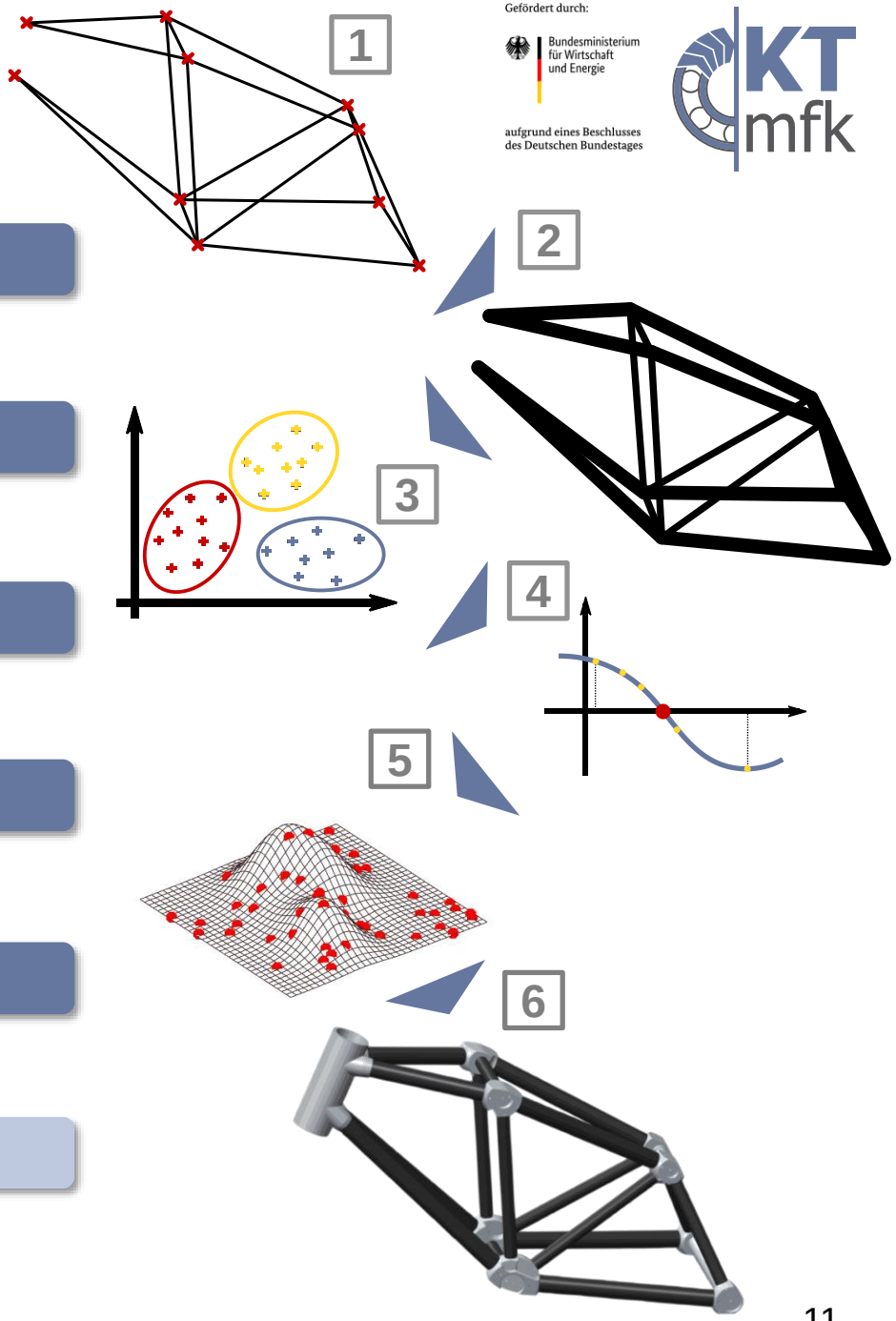
aufgrund eines Beschlusses des Deutschen Bundestages

1. Create/Import Skeleton Structure
2. Dimensioning of Strut Profiles
3. Clustering of Struts Profiles
4. Solving with Bisection Method
5. Optimize with Genetic Algorithm
6. Generate CAD Model



Validation
Overview

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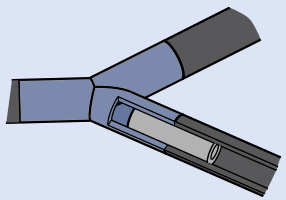
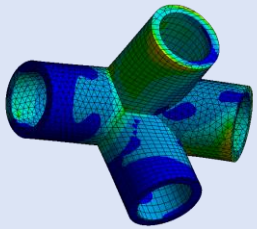
aufgrund eines Beschlusses des Deutschen Bundestages

System Validation

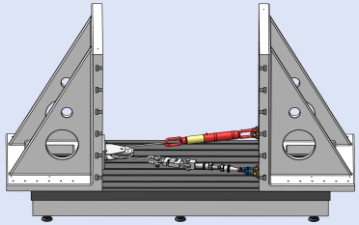
CAD-Model



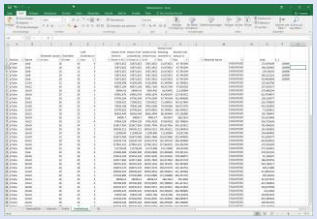
FEA Simulation

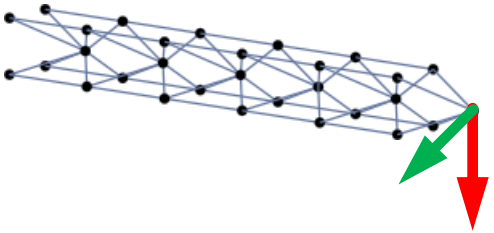


Prototype Test

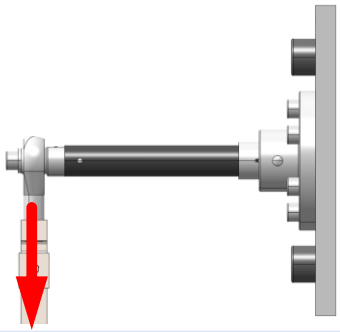


Component Characterisation





Load Cases



Part Tests

Joint Tests

Validation
Testing Equipment

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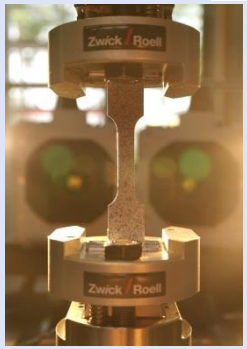
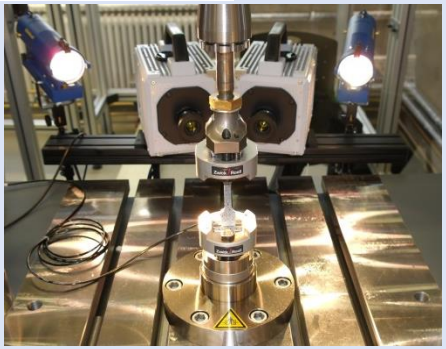
High speed test rig Zwick HTM5020

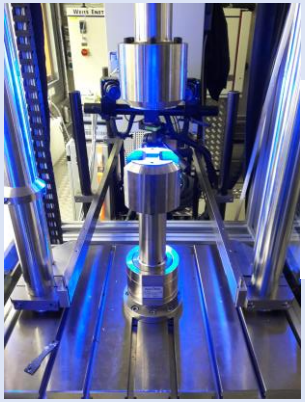
Picture source: Zwick

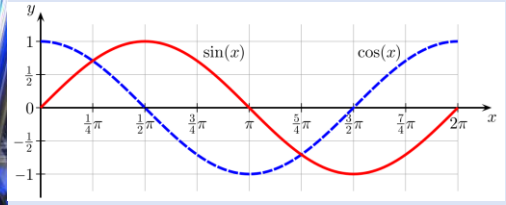




Performance of highly dynamic tensile and compression tests (0,001 to 20 m/s)

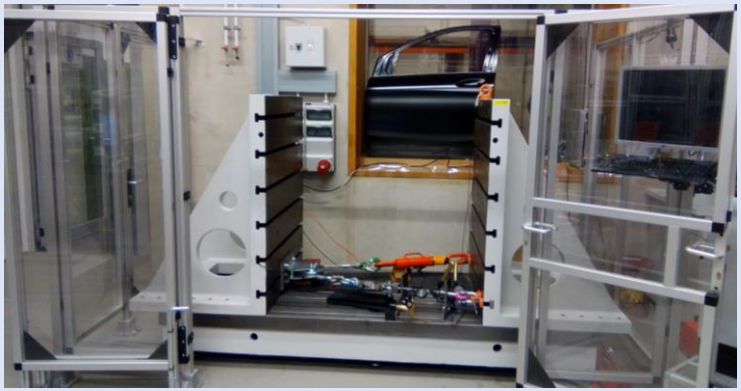
Servo-hydraulic Pulser Zwick HCT 25/250





Cyclic continuous loads up to 25 kN / 250 Nm / 30 Hz

Modular stiffness test rig "Bärenfels"



Testing Equipment

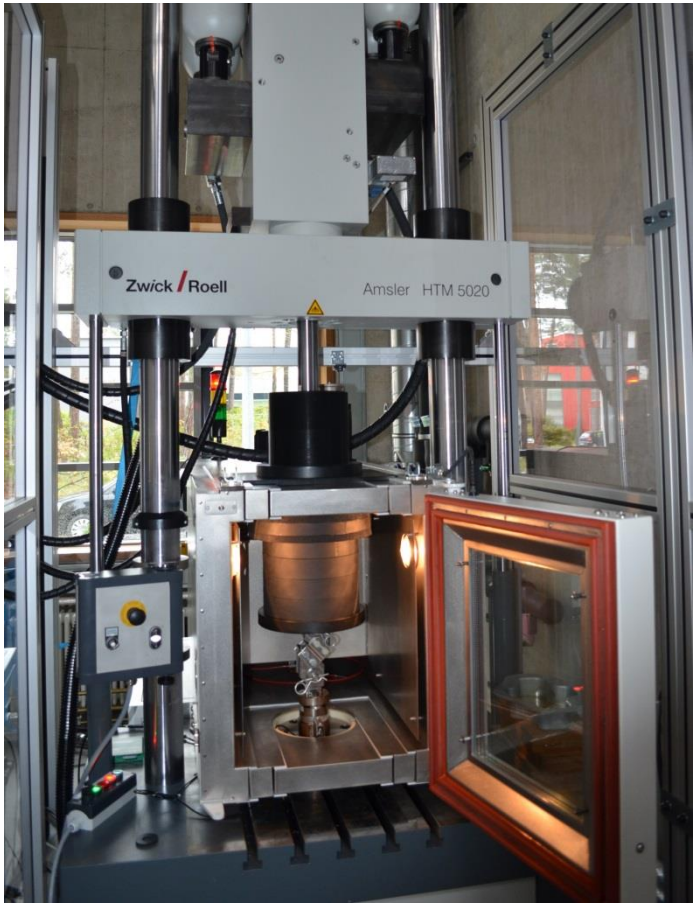
High speed test rig - Zwick HTM 5020

Testing system

- Servo-hydraulic high speed testing machine
- Tests with up to **20 m/s, 50 kN**
- Attainable strain rates up to **1000 s^{-1}**
- Optional: Temperature control **-60 …+150 °C**

Determinable parameters (e.g.)

- Anisotropic (tensile-)elastic and shear moduli
- Transversal contraction
- Flow curve or Johnson-Cook-Parameters:
  - Yield stress
  - Strain hardening modulus and – exponent
  - Strain rate coefficient
- Failure parameters

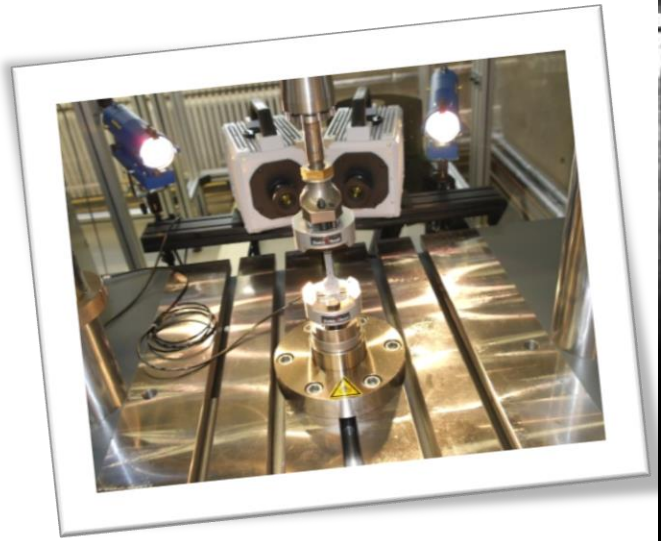


Testing Equipment

Optical strain measurement - GOM ARAMIS 3D HHS

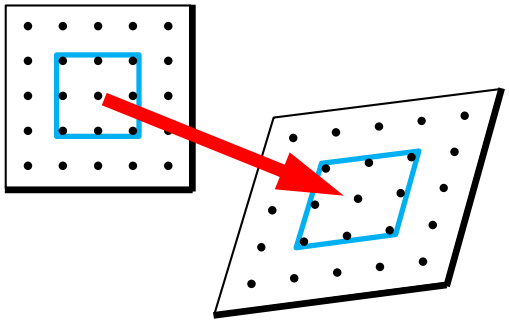
High speed cameras

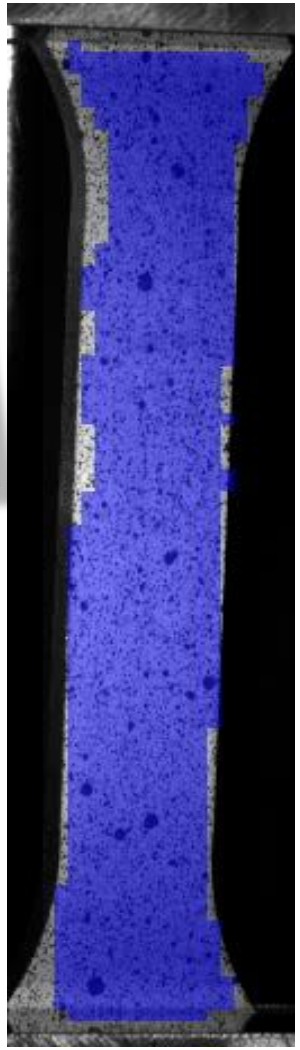
- Recordings up to **150.000 fps**
- Stereoscopic arrangement
- **0,01% - 100%** strain resolution



Grey value correlation

- Determination of strains by relative displacement of speckled areas
- Identification of necking and thickness decrease





Example

- Tensile test, test speed 5 m/s
- Recording with 60.000 fps, strain superimposed

Testing Equipment

Servo-hydraulic Pulser - Zwick HCT 25/250

Motivation

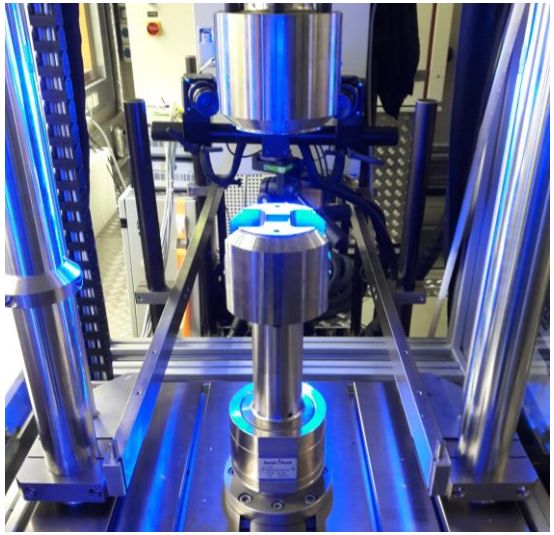
- Considering non-linear fatigue damage evolution of composite parts

Test forces and moments

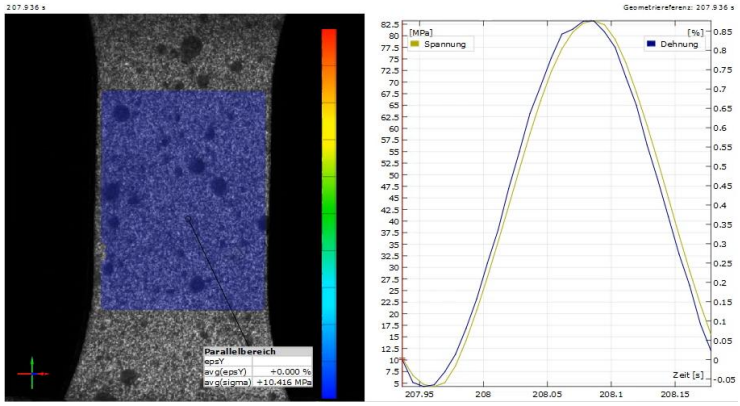
- Axial force max. ±**25 kN**
- Torque max. ±**250 Nm**
- Frequency f = **15 Hz**

Signal shape and load control

- Sinusoidal oscillation
  - Fixed minimum load F_{min} = 0,1 kN
  - Maximum load F_{max} depending on fibre orientation and load state
  - Frequency f = 4 Hz



Zyklische Be- und Entlastung



Testing Equipment

Modular stiffness test rig – “Bärenfels”

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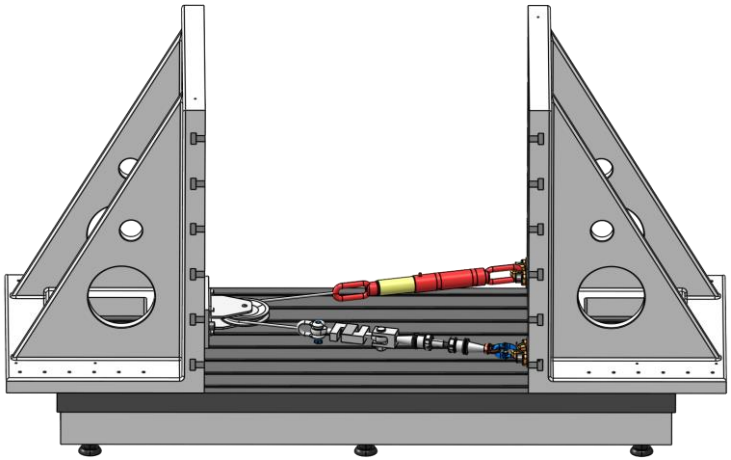
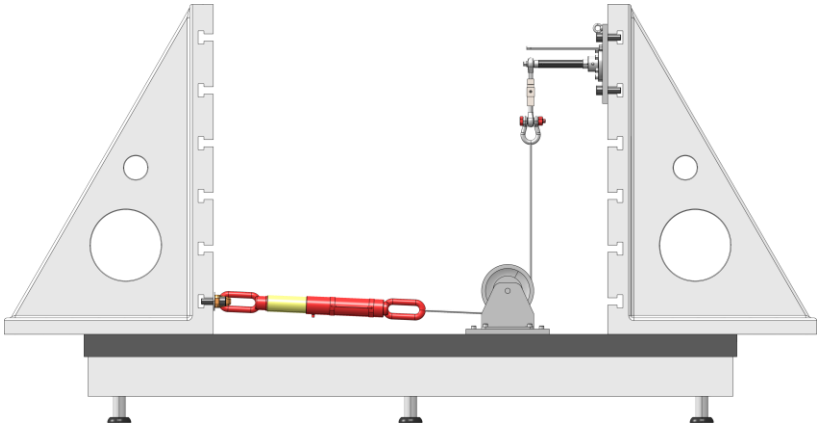
Testing system

- Static stiffness and strength testing
- Modular structure



Test forces and sizes

- Test load up to **100 kN**
- Test track up to **1250 mm**
- Test items up to **1300 x 1250 x 1000 mm**



Summary

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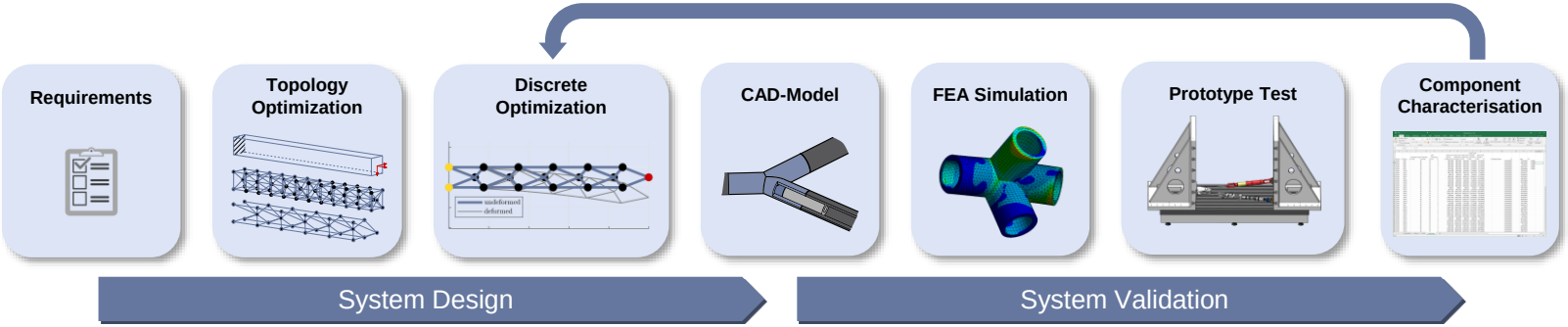
- Multi-Material structures are utilizing specific material properties
- Reduction of costs by standardization and modularization

- Automated holistic design process for multi-material truss structures



- Component and system tests to characterize semi-finished products and provide information for additional mass reduction