Microcellular polyurethane as steering coupling element

Material specific properties of solutions based on Cellasto®-Elastolit-X® composite structures

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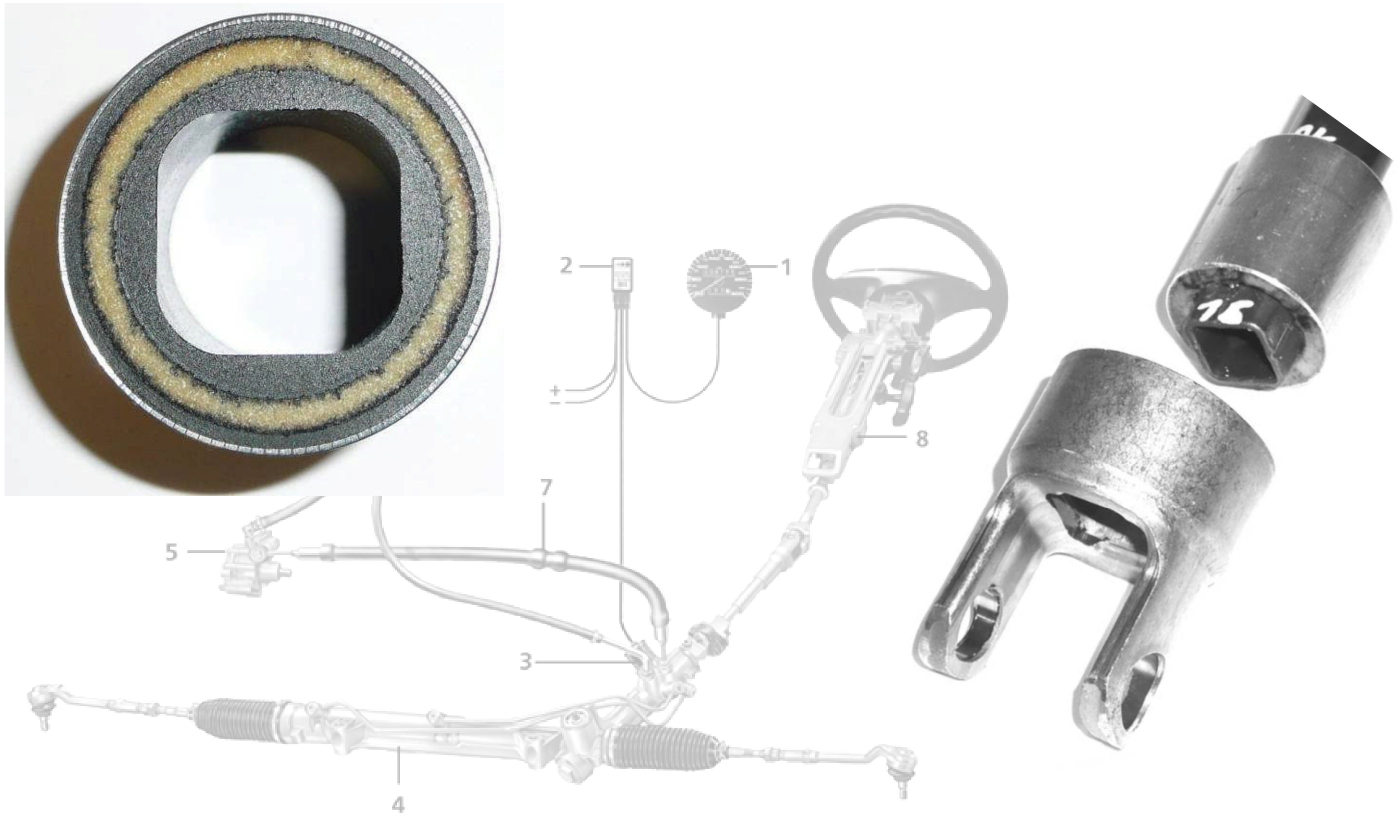

Contents

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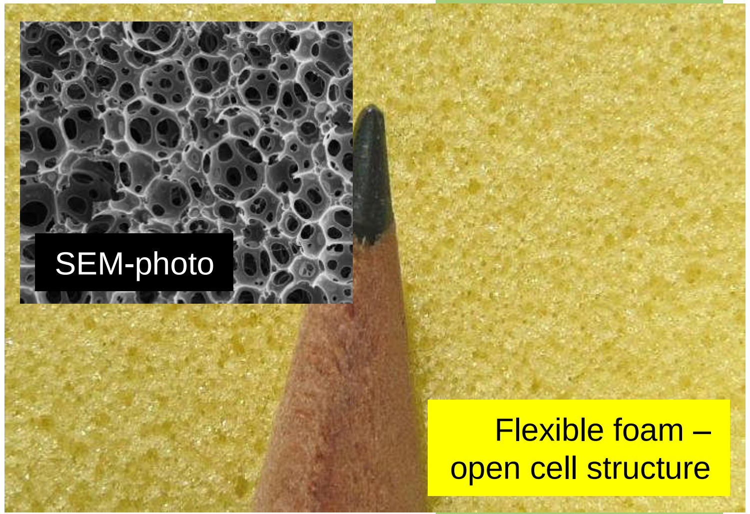
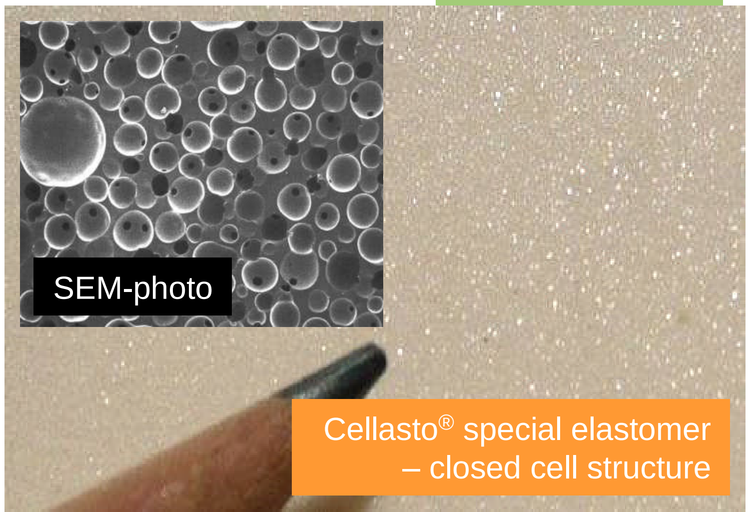
Material specific properties

Classification, material structure, production

- Cellasto® = microcellular polyurethane that is applicable as technical elastomer
- Cellular material structure with
  - Volume compressible air component
  - and a rubber-like matrix
  - high density (350-650kg/m³)
  - Very closed cell structure
  - Molecular level: hard & soft segments
- Cellasto® necessitates a specialized and challenging production process.





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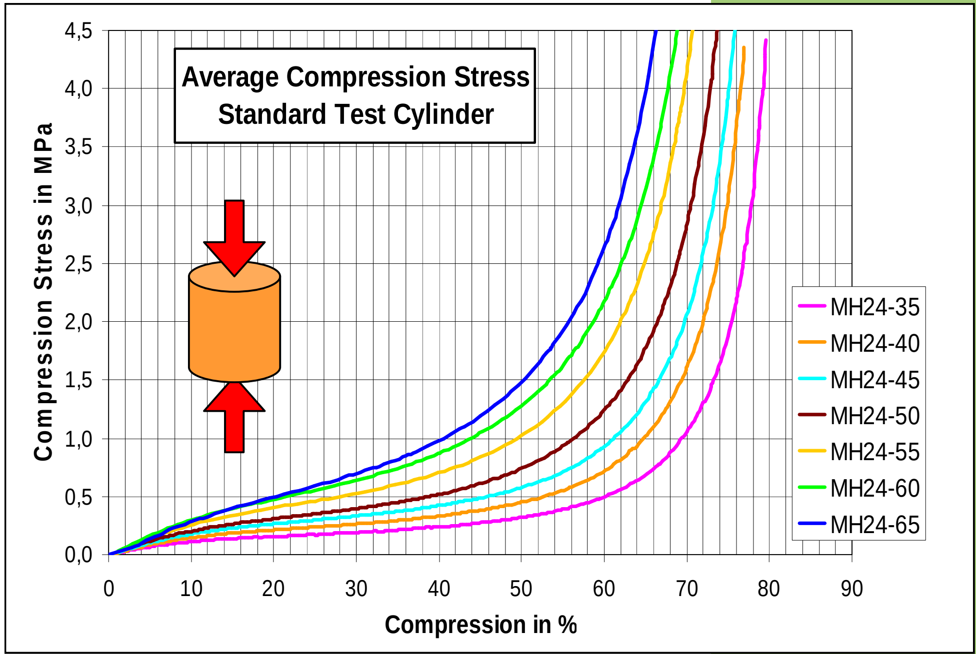
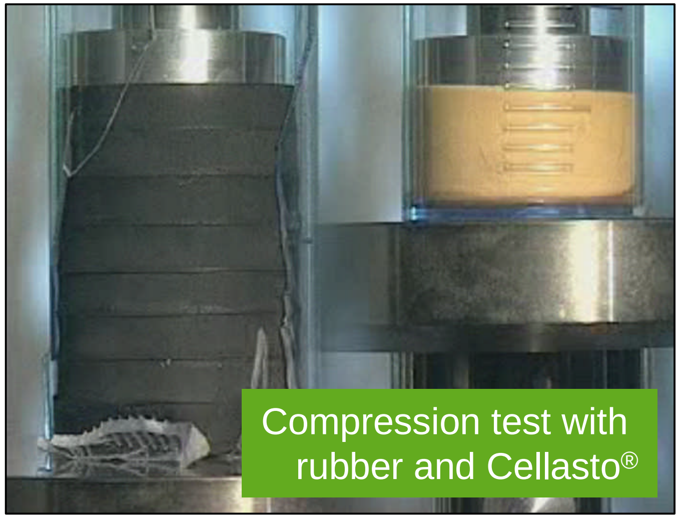
Material specific properties

Compressive stress and effect of volume compressibility

- Compression test with a cylindrical specimen:
  - Compression and displacement of the air component
  - At the beginning the lateral extension is negligible and raises at high compression levels
  - The stiffness and the maximal deformability is highly dependent on the density
- Compressing rubber and Cellasto® samples in a glas tube demonstrates the effect of volume compressibility





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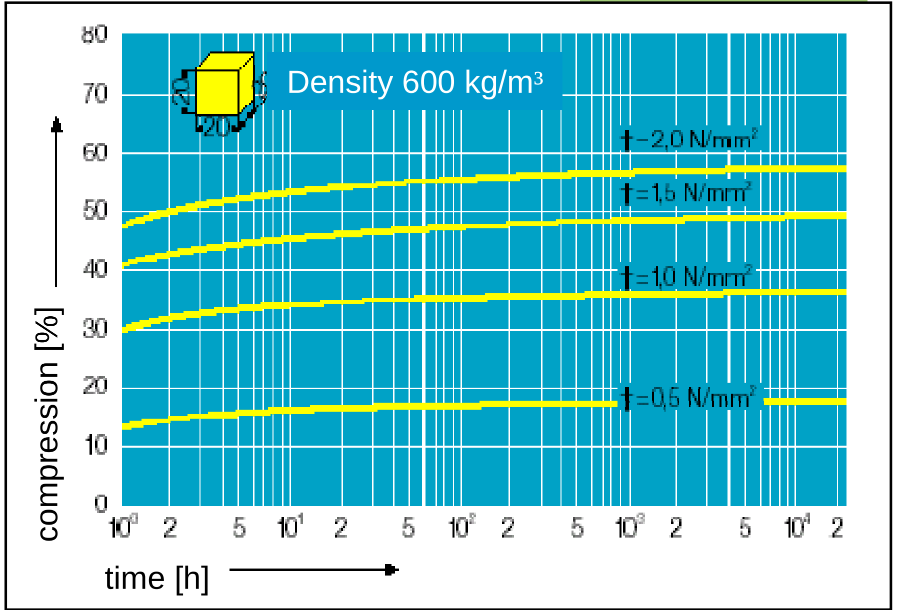
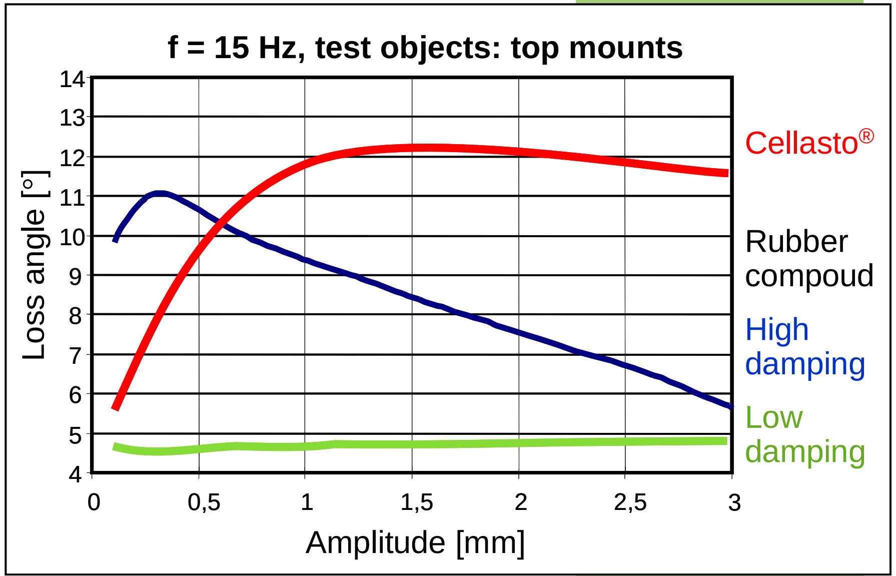
Material specific properties

Setting, dynamical characteristics and others

- Statical compression set:
  - Taking into account when dimensioning parts
  - Extent of creeping very small compared to the reversible deflection
- Dynamical properties:
  - Favourable stiffening properties for many applications
  - Dependent on state of stress and material density
  - Amplitude dependent damping
  - Outstanding fatigue limit for compression stress
- Characteristics such as elongation break, tear resistance, heat aging and so on are fully competitive for many automotive applications.





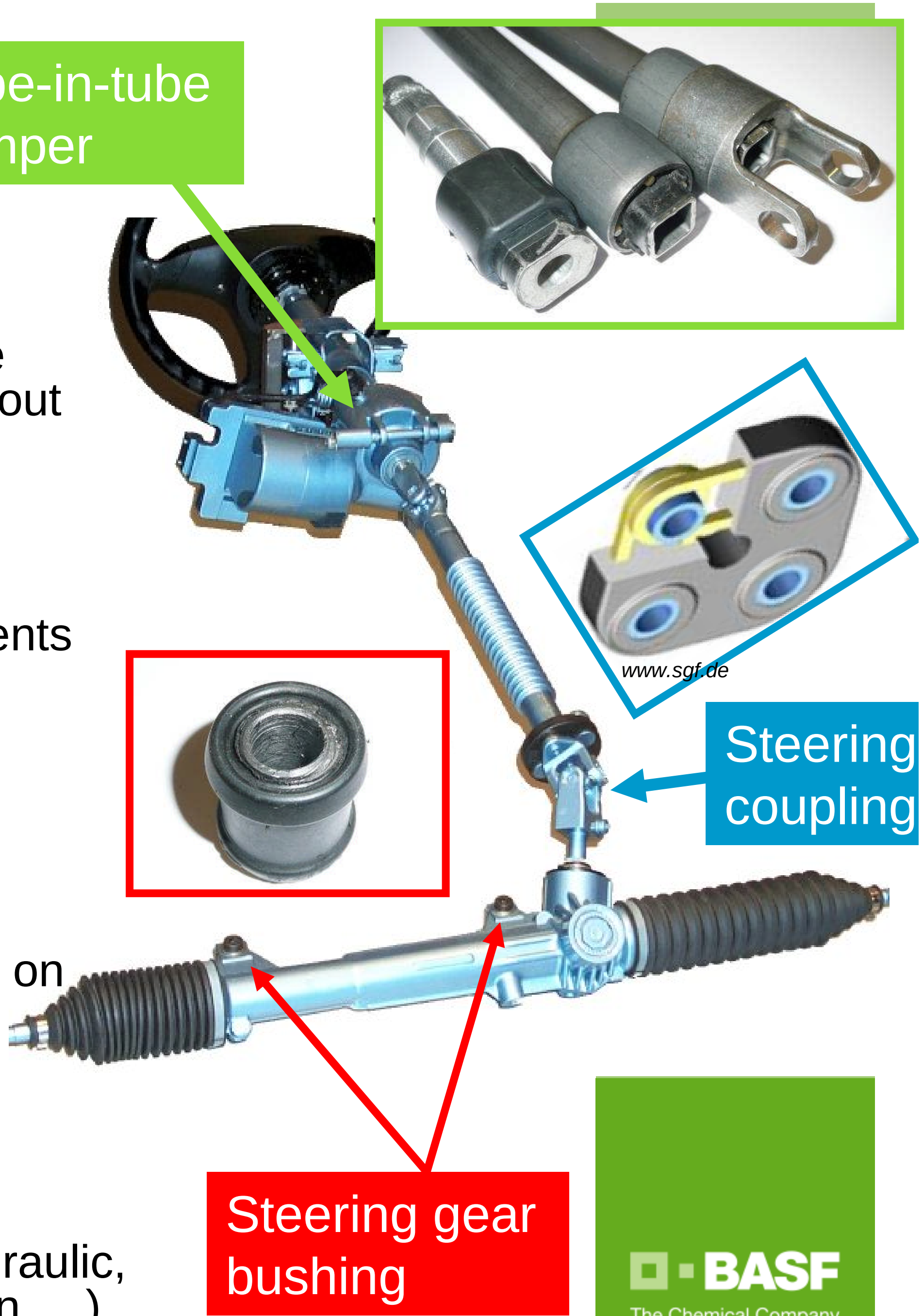
Material specific properties

Examples of automotive applications

Steering couplings

Function in steering systems

- Steering systems need to
  - Transmit and reinforce input from the steering wheel and give feedback about the road.
  - Decouple acoustical excitations and vibrations excited by uneven roads.
- Decoupling is realized by damping elements like
  - Tube-in-tube dampers
  - Steering couplings
  - Bushings for the steering gear
- There exist different solutions depending on
  - The engine‘s orientation
  - The car‘s market segment
  - The manufacturer‘s philosophy
  - The steering system technology (hydraulic, electrical, point of torque amplification, ...)



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Steering couplings

Requirement specification

- Torsional stiffnesses between some Nm/° and about 30Nm/° are required.
- The torsional load spectrum depends on the position relative to the torque amplifier.
  - position before the torque amplifier ► max. torques seldomly higher than 1-6Nm.
  - Otherwise the torques can reach much higher values.
- Steering couplings have to withstand extreme axial loads (10-15kN) due to crash or mounting procedures.
- Low axial stiffness is desirable for improving the vibrational comfort.
- They have to come up with a redundance in case the elastomer part is destroyed.
- As far as we know there is no radial function.
- The damping elements also need to decouple acoustical excitation:
  - from the wheels
  - from sources like electrical or hydraulical actuators
  - the steering column as noise transferring path could become more relevant with electrical powertrains.
- Load peaks have to be reduced.
- Temperature requirements vary very much with the couplings position.
- ► Solution in Cellasto feasible?

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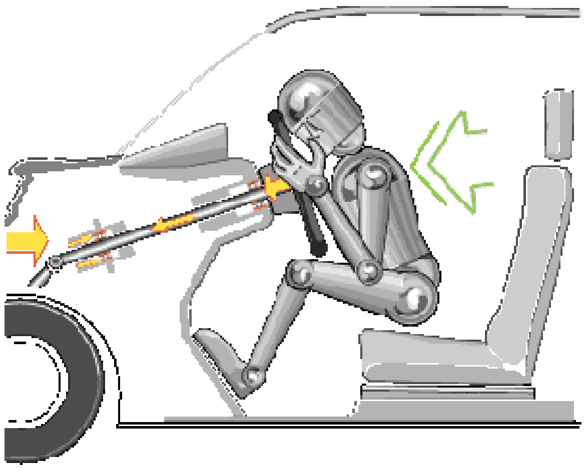
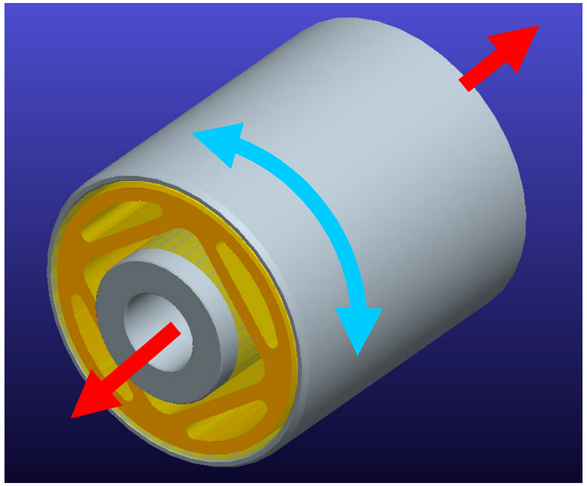
Composite technologies

Motivation for combining Cellasto® with harder materials





- Multi-axial loads are common with many automotive applications for elastomers.
- Tensile and shear forces between Cellasto and metal surfaces can be transferred via friction or chemical bonding.
- Use of friction is limited and implicates the danger of sliding.
- Steering couplings such as tube-in-tube-dampers need to
  - withstand high axial forces due to light crash, mounting and repair processes.
  - Prevent rotational Sliding for some designs.

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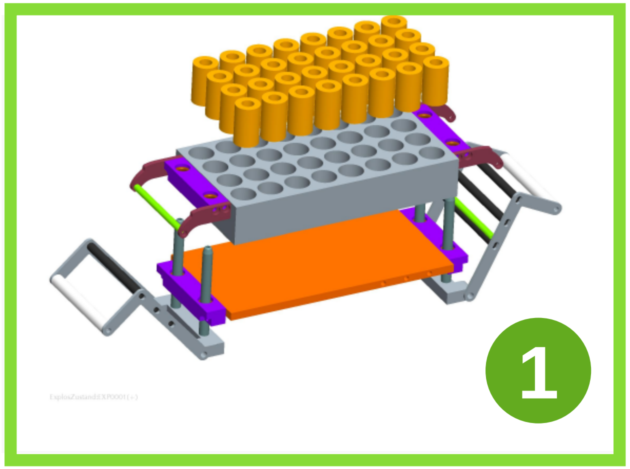
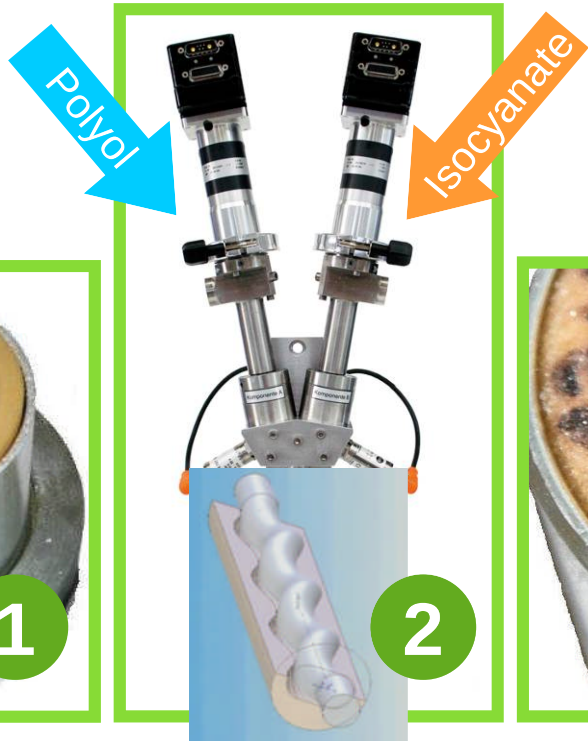
Composite technologies

Production of composite structures





1. Mold charging:
   - Semifinished products e.g. water-cutted Cellasto-profiles
   - Metal parts treated with bonding agent
2. Component dosing and pressure-free mold filling by static mixer
   - Dosing of polyol and isocyanate ► very liquid resin „Elastolit X“
   - „Elastolit X“ fills out fine and detailed cavities, can be reinforced by fiber glass (e.g. for replacing metal parts)
3. A composite structure with strong adhesion between layers of Cellasto®, Elastolit X and a hard material is realized.

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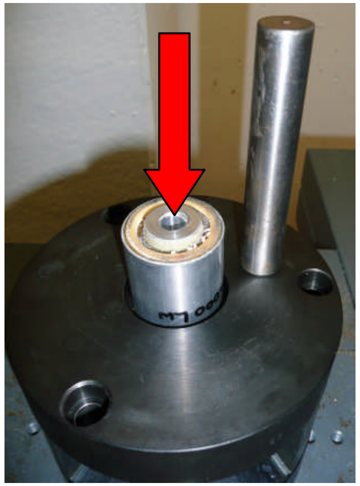
Composite technologies

Validating the adhesion characteristics



- Cellasto-Elastolit-X material samples have been used for
  - finding appropriate bonding agents and
  - testing the system‘s adhesive strength.
- The composite structure‘s adhesive strength exceeds Cellasto‘s tensile strength which is absolutely competitive compared to rubber compounds.
- These results have been further verified by destructive testing of prototypes.
- A steering coupling prototype with about 40mm in Ø and 45mm in length supports up to 14kN in axial direction whereby the requirement was 13kN.

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Experimental prototype data

Photos, global geometry, overview of experimental data

- Different Cellasto prototypes and rubber bushings
- Comparable use of design space:
  - Lengths: 25mm - 45mm
  - Outer-Ø: 33mm - 38mm
  - Thickness elastomer: 3.5–4.5 mm
- Statical and dynamical testing:
  - torsional
  - axial
  - radial
- Axial and Radial also in frequency range of 3kHz - 5kHz
- Setting as consequence of the first torsional load
- Endurance tests

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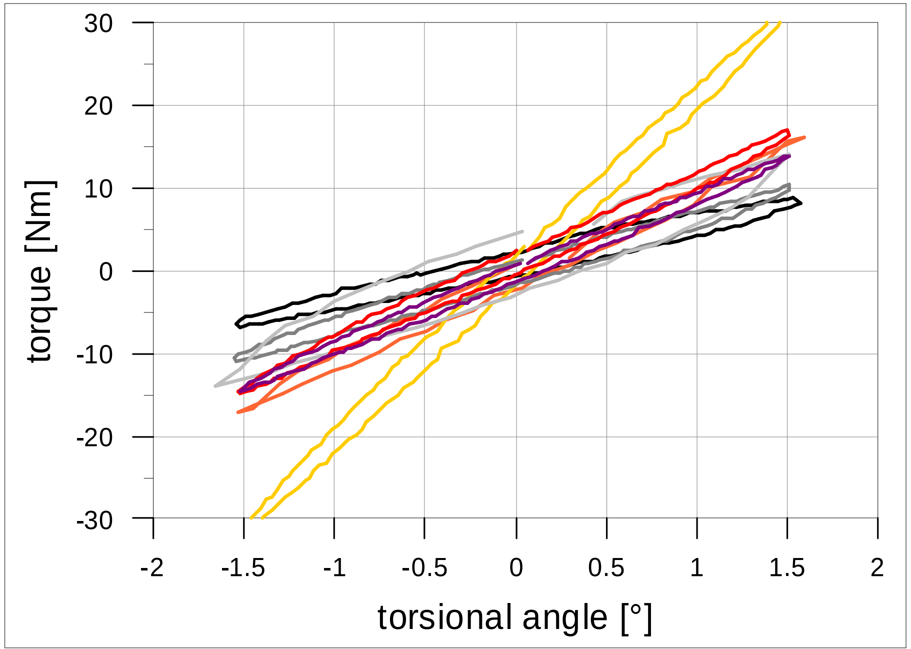
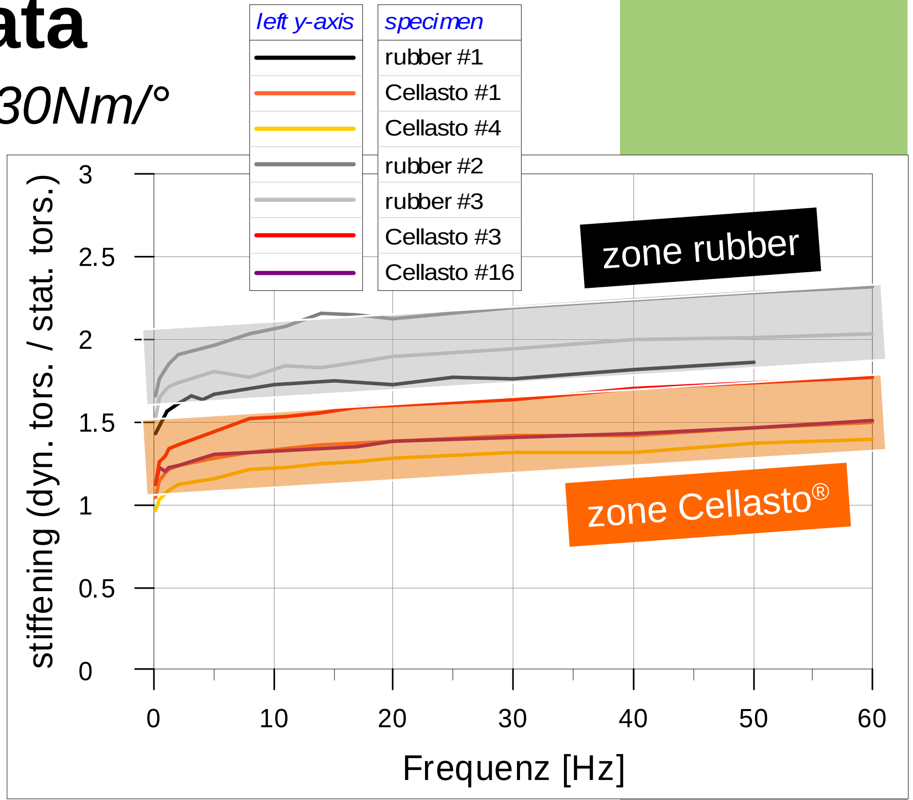
Experimental prototype data

Statical torsion, preconditioning: +/-4°, 30Nm/°





- Preconditioning of the specimen
- Statical torque-angle-of-rotation-curve
- Torsional stiffness for Cellasto prototypes higher (+less design space!)
- ► softer and more progressive characteristics are easily realizable
- Less friction in Cellasto‘s hysteresis
- The stiffening as relation of the dynamical torsional stiffness and the statical torsional stiffness shows much lower values for Cellasto

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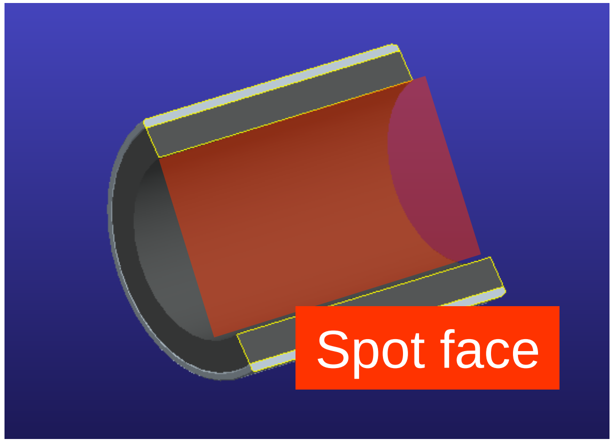
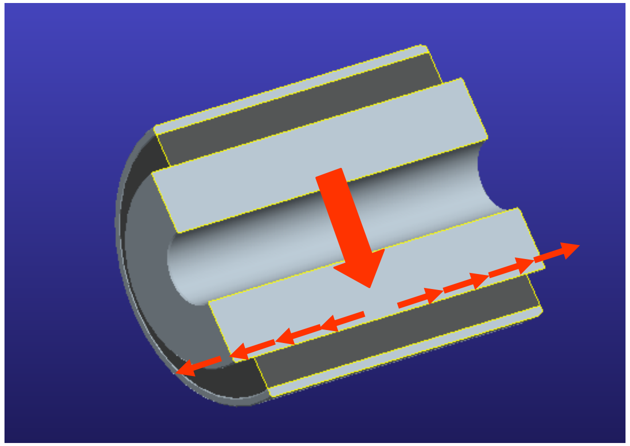
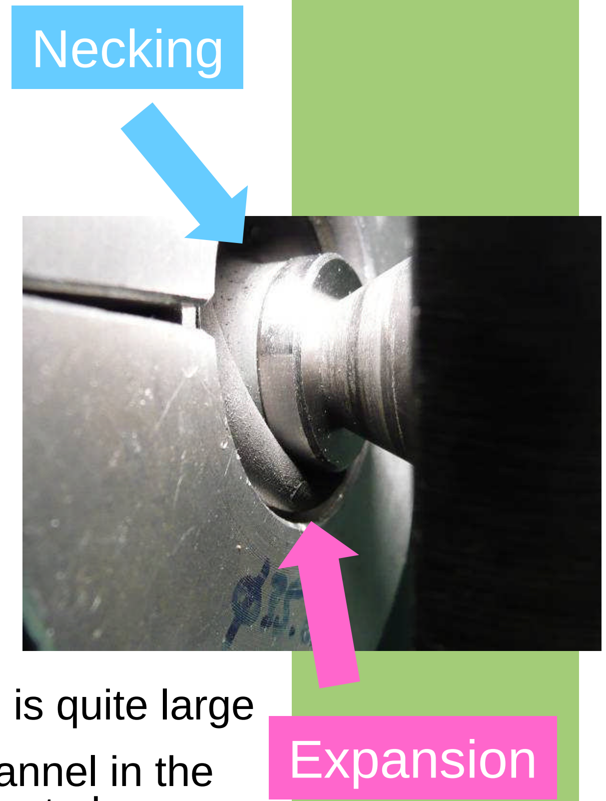
Experimental prototype data

Reaction on compression load
and bushing properties for a rubber bushing







- the rubber‘s spot face in the radial direction of a typical bushing is quite large
- Radial loads will force the rubber to evade through a narrow channel in the axial and circumferential direction, since the rubber‘s volume has to be maintained
- The high resistance versus this deformation is equivalent to high radial stiffnesses
- the shear stresses that are used for tranferring axial and torsional loads will cause lower stiffness values
- A Cellasto bushing will show a different behaviour because it can react on the radial load with its ability to shrink

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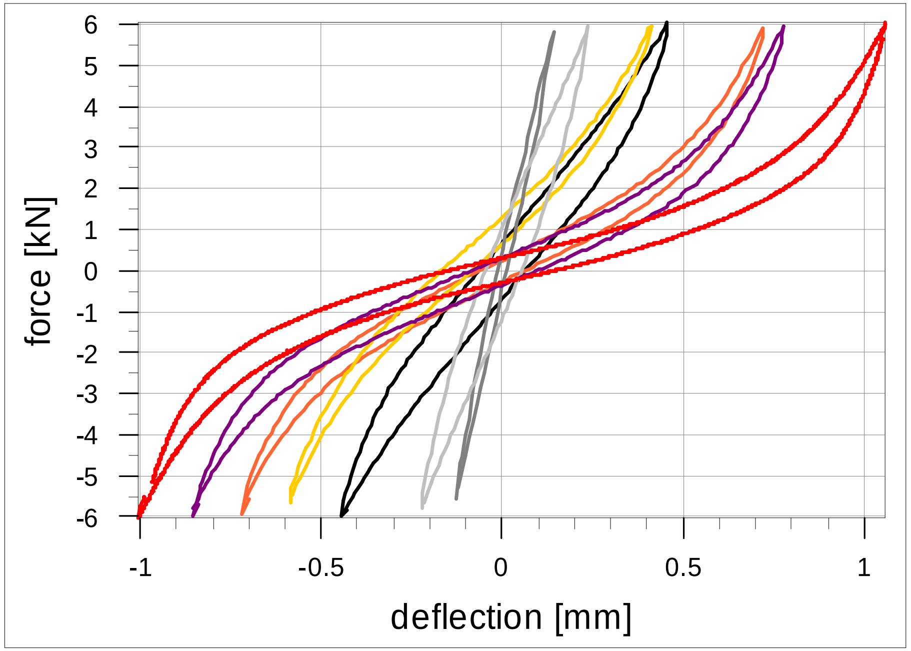
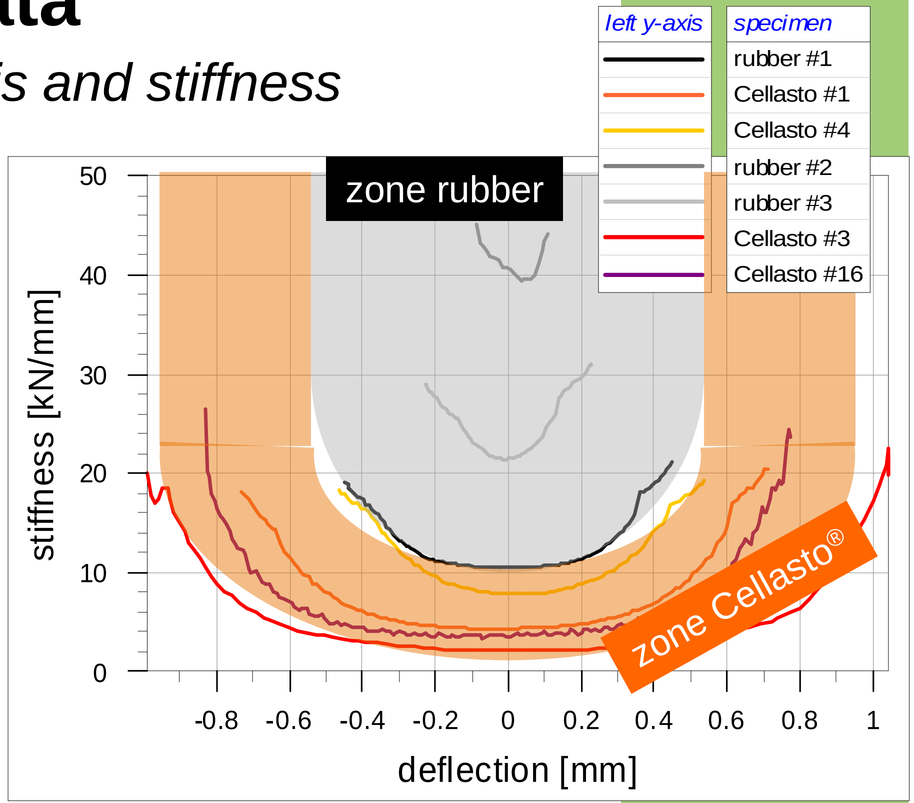
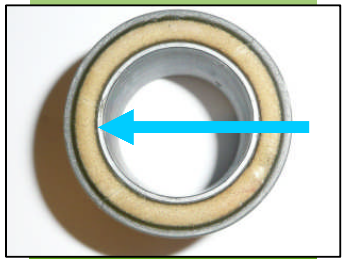
Experimental prototype data

Radial characteristics, statical hysteresis and stiffness







- The test bench‘s stiffness has to be taken into account because of a high stiffness level and very small maximal deflections
- Preconditioning by radial loads and torsional testing
- Measurement cycles force controlled ► different deflection amplitudes
- Therefore the comparability of stiffness values is constrained
- The radial stiffness is much higher for the rubber mounts because of the volume-incompressiblity
- ► higher potential for acoustical isolation

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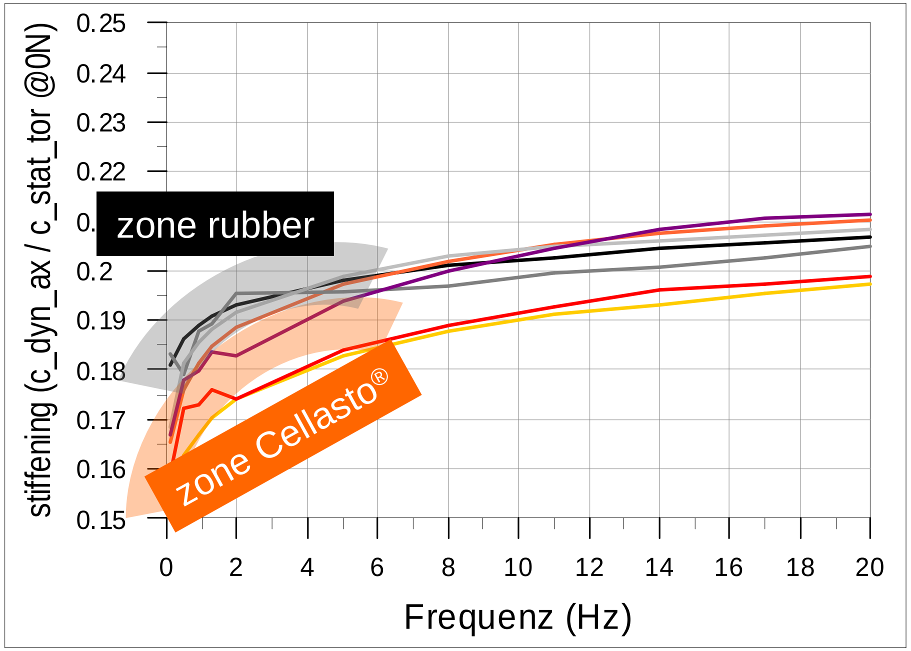
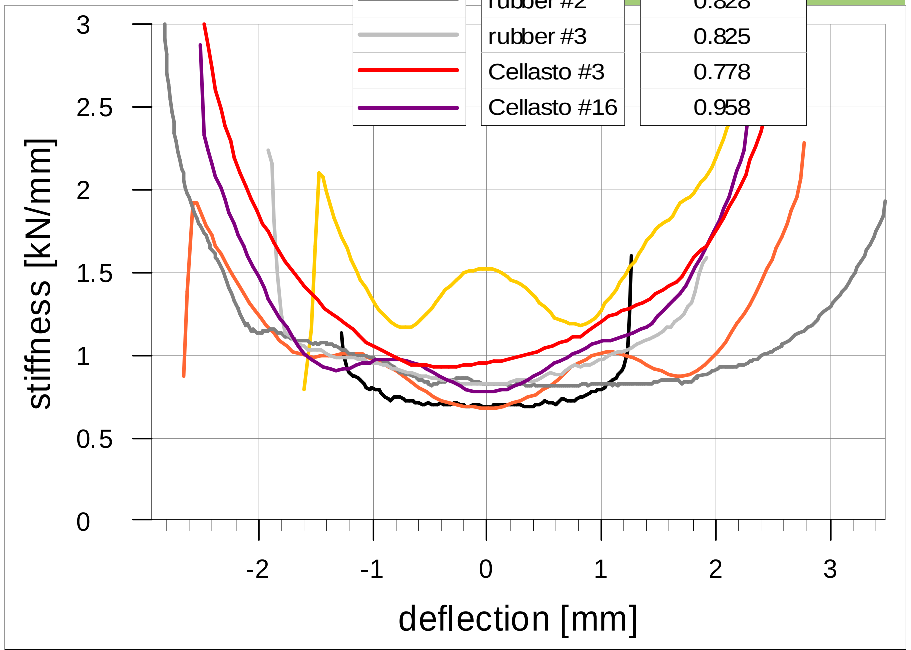
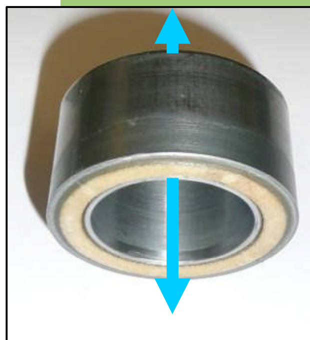
Experimental prototype data

Axial characteristics, statical hysteresis and stiffness

left y-axis	*specimen*	*c(0N) [kN/mm]*
black	rubber #1	0.690
orange	Cellasto #1	0.764
yellow	Cellasto #4	1.311
dark grey	rubber #2	0.828
light grey	rubber #3	0.825
red	Cellasto #3	0.778
purple	Cellasto #16	0.958







- Preconditioning of the specimen
- Statical force-deflection-curve and stiffness-deflection-curve
- Force-controlled ► different deflection amplitudes
- Comparability is limited because of the amplitude dependency
- Bushings using the same design space are statically softer
- Stiffening as dynamical axial stiffness at amplitude 0.5mm divided by statical torsional stiffness @+/-1.5Nm after setting cycles

Experimental prototype data

amplitude dependency, driving situations and angle of torsion

Slow statical steering at high speeds ► acoustical isolation & stiffness around 0°

Maximal torque during parking situation

Vibrations as consequence of an uneven road surface ► axial stiffnesses / torsional stiffening?

Dynamical steering at average speeds ► statical torsional stiffness

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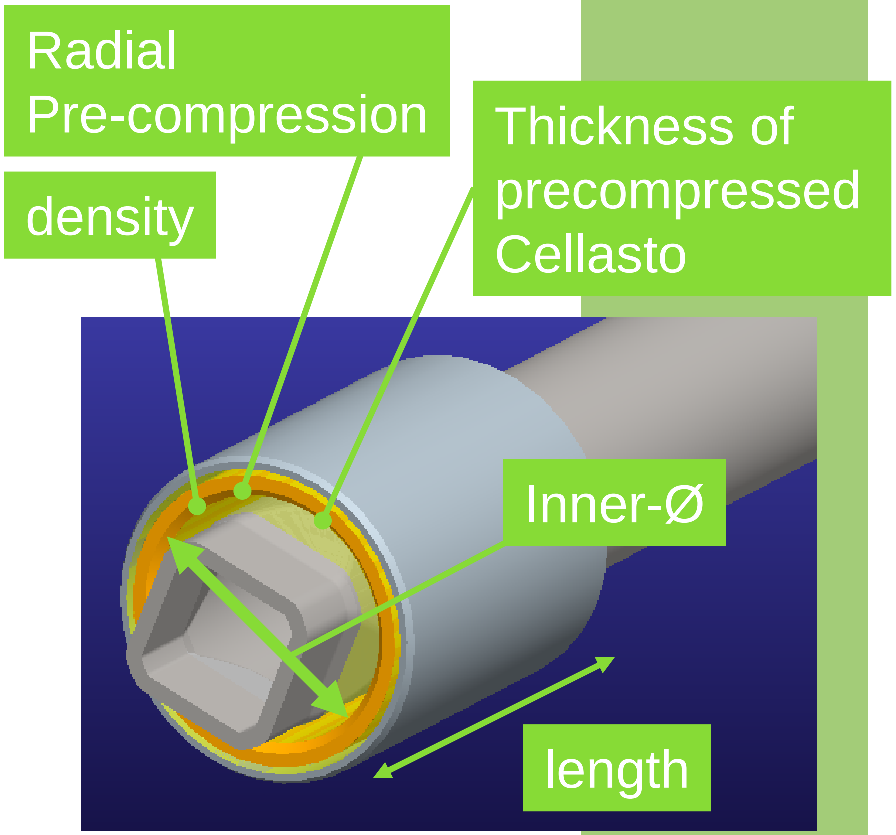
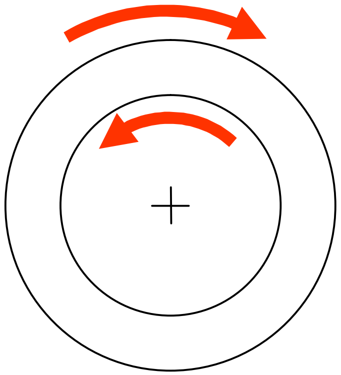
Optimisation potential

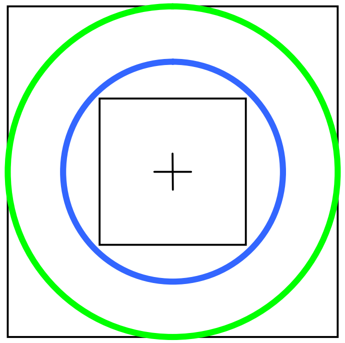
Overview of design parameters

- The Cellasto bushing offers different design parameters (see the picture).
- The parameters directly influence the parts properties and offer optimisation potential.
- An important variation of the shown concept are designs that do not only make use of tensile stress but also of compression.
- This can be realized by non-circular profiles.

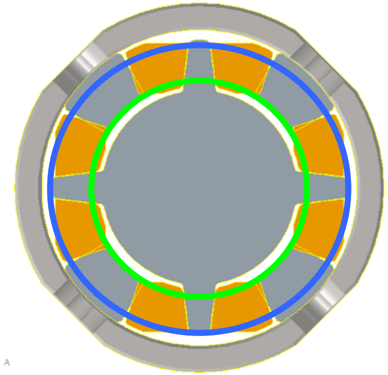




„Pure“ tensile sress



Little tensile stress, Compressive stress



Extreme design, almost only compression

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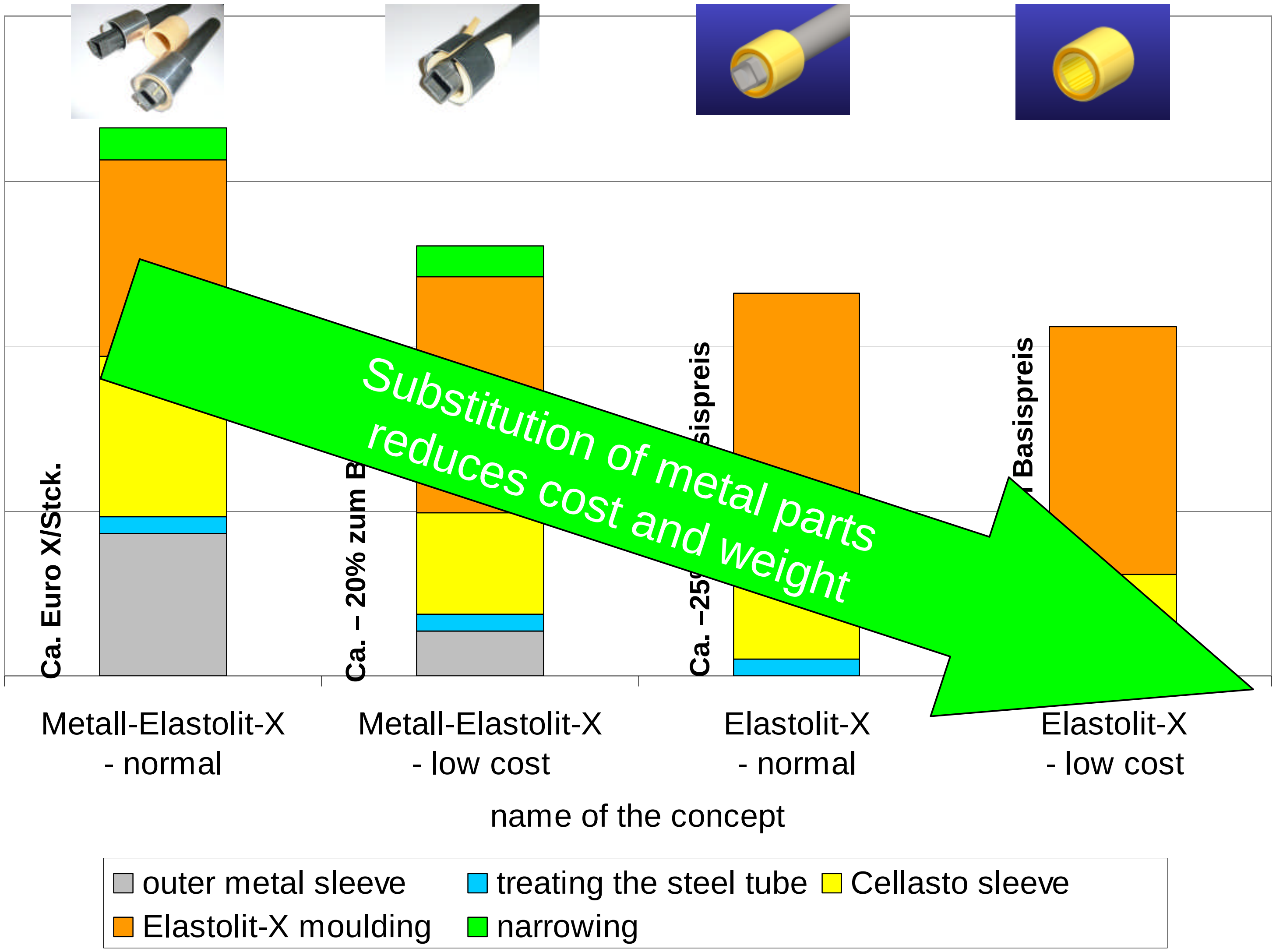
Optimisation potential

costs for different design concepts



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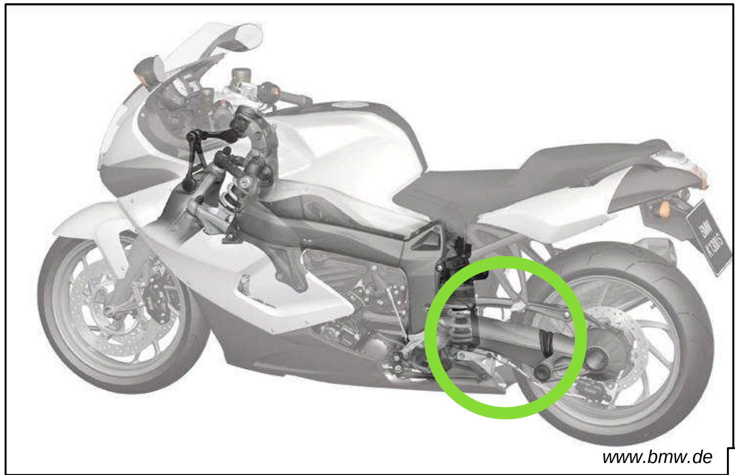
References

Torque transfering and decoupling parts



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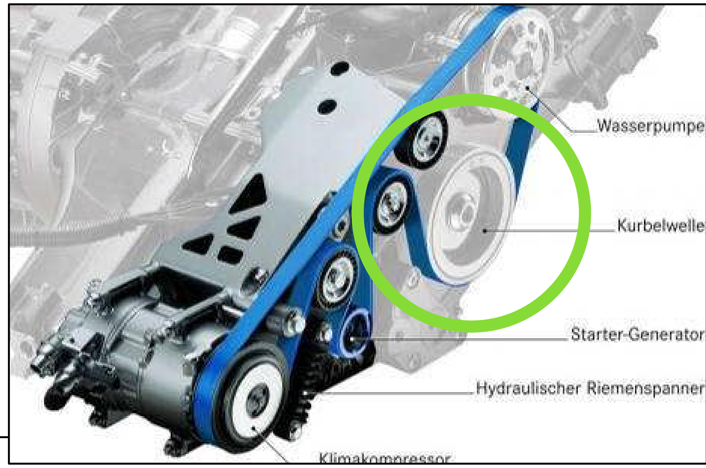

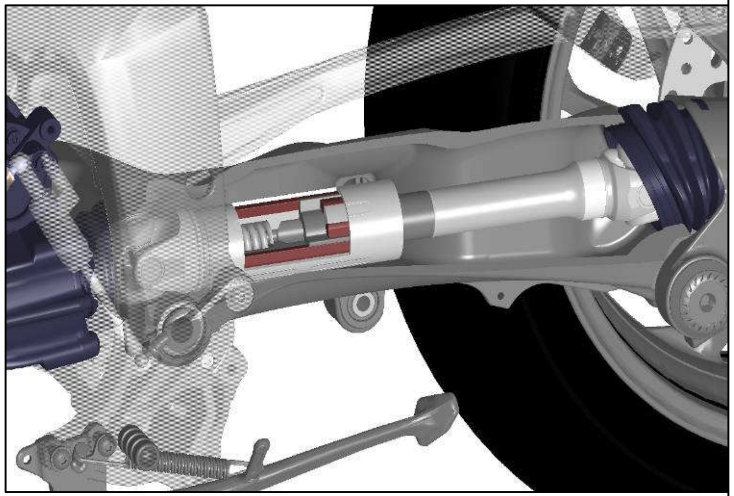

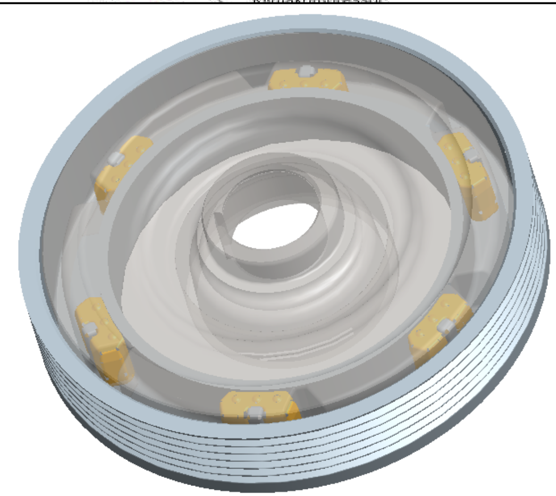

Torsional load change damper in cardan shaft for motorcycles

Damping element in pulleys for start-stopp-systems

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Summary

- Cellasto® is microcellular polyurethane that can be used as elastomer for sophisticated technical applications.
- A composite technology based on the resin system Elastolit X allows bonding of Cellasto to hard structures.
- Part designs are realizable that can fulfill all requirements for steering couplings and other torsional busings:
  - tests with Tube-in-tube bushings are running.
  - coupling-like concepts can still be worked out.
- A steering coupling based on Cellasto® offers some advantageous characteristics:
  - Saving design space, substitution of metal parts (price, weight)
  - More freedom for realization of L-D-curves (e.g. higher torsional stiffness, more progression)
  - Very different axial and radial characteristics
- The chances of these concepts in a rapidly changing steering system market are currently elaborated.

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