Hegewald & Peschke
Meß- und Prüftechnik GmbH

Material Testing on Plastics and Composites

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Content

- What are Plastics?
- Material Testing on Plastics
- Test & Standards
- ISO527:2012; changes towards THE version from 1993
- Requirements on UTM
- H&P solutions for polymer mechanical testing
  - Machine configurations
- Applications / Examples

Plastics

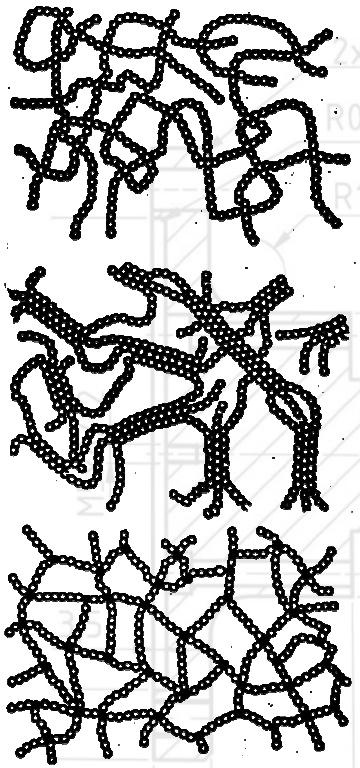
"any one of a large number of synthetic usually organic materials that have a polymeric structure and can be moulded when soft and then set, esp. such a material in a finished state containing plasticizer, stabilizer, filler, pigments, etc. Plastics are classified as thermosetting (such as Bakelite) or thermoplastic (such as PVC) and are used in the manufacture of many articles and in coatings, artificial fibres, etc." https://CollinsDictionary.com

"Plastic is a material consisting of any of a wide range of synthetic or semi-synthetic organics that are malleable and can be molded into solid objects of diverse shapes. Plastics are typically organic polymers of high molecular mass, but they often contain other substances. They are usually synthetic, most commonly derived from petrochemicals, but many are partially natural.[2] Plasticity is the general property of all materials that are able to irreversibly deform without breaking, but this occurs to such a degree with this class of moldable polymers that their name is an emphasis on this ability." https://en.wikipedia.org/wiki/Plastic

Plastics

The mechanical properties depend on:

- chemical constitution
- primary structure
  - tacticity of ligands
  - isomery (head-tail, stereo, rotation)
  - branches
  - chemical blocks
  - grafting structure
  - molecular weight
  - crosslinks
- secondary structure
  - Thermoplastics – amorphe or semi crystalline
  - Duroplastics – mainly crosslinked
  - Elastomers – mainly crosslinked



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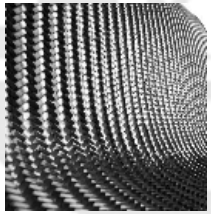
Plastics

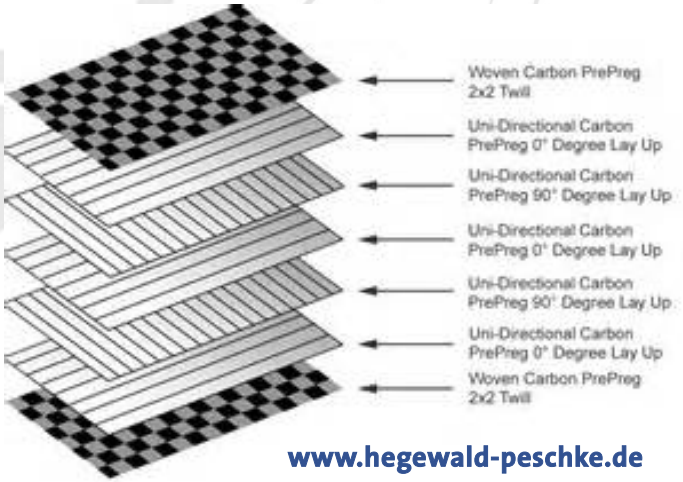
Low cost – ease of manufacturing – versatility – mainly organic compounds
Extruded-Injection molded-Textiles-Foils-Packaging-Yarns-Composites-Blends-…

Thermoplastic Extrudes

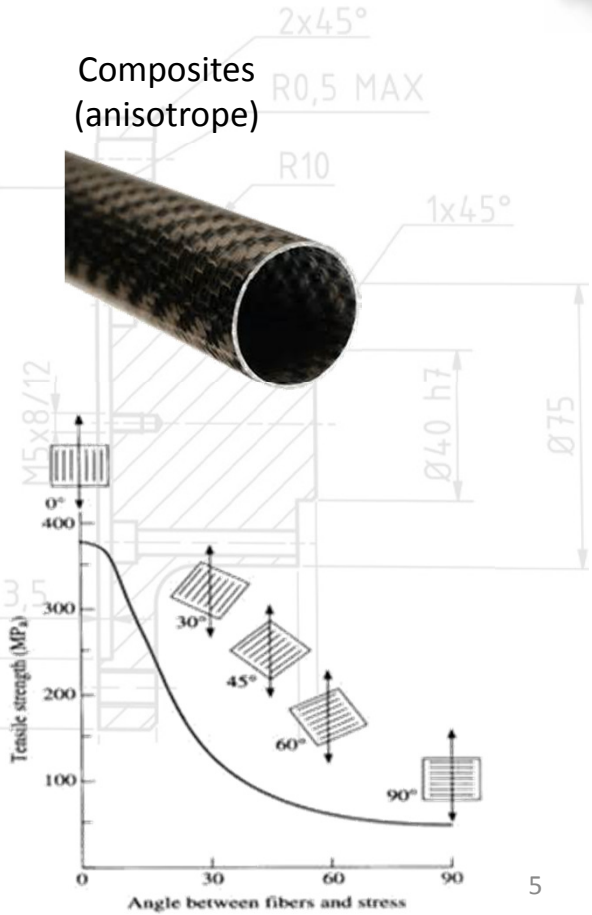


Polymer Blends

Fillers (isotrope)



Composites (anisotrope)



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Tests and Standards

	Palstics	Elastomers
Tensile test	**ISO 527, ASTM 1708, ASTM 638, ISO 1926, ISO 1798** **carbon composites** **DIN EN2561 (UD Laminate 0°)** **DIN EN 2597 (UD Laminate 90°)**	**ISO 37, DIN 53504, DIN 53354, ASTM 412**
Bending test	**ISO 178, ISO 1209, composites: DIN EN ISO 14125**	
Compression test	**ISO 604, ISO 844, ISO 3386, composites: DIN EN ISO 14126**	**ISO 7743, ASTM D575**
Tear/Shear test	**ISO 1922, composites: DIN 65148, DIN EN 2563**	**ISO 34, DIN 53515, DIN 53356**
Pendulum impact	ISO 179, DIN 53453	**Adhesives** Peel resistance ISO8510, ISO4578, ISO11339 Shear test ISO4587, ISO10123
5mm ball Hardness	DIN 53456	
Shore hardness	DIN 53505	
VICAT	ISO 306, DIN 53460	

Tests and Standards

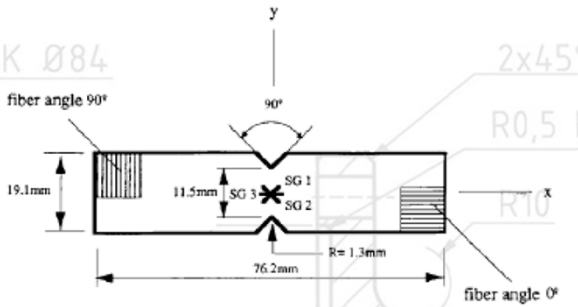
Static tests

Iosipesco test

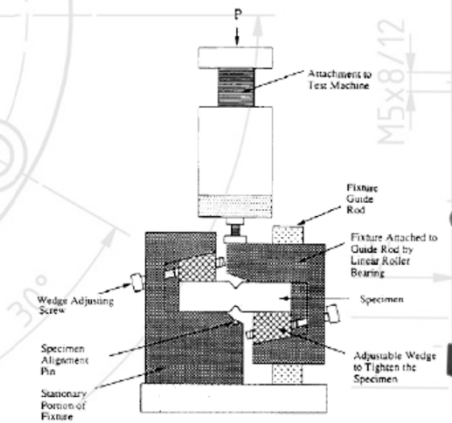
Application: DU Laminate, Cross Ply
Standard: ASTM D5379

Advantages:
Cost-effective specimen preparation
Very accurate test results
Test bench for simple compression test
Standardized according to ASTM D5379

Disadvantages:
Special specimen holder
No pure shear load



Test specimen, grain direction 0° or 90° [1]



Scheme Wyoming experimental setup [1]

Specimen holder [2]

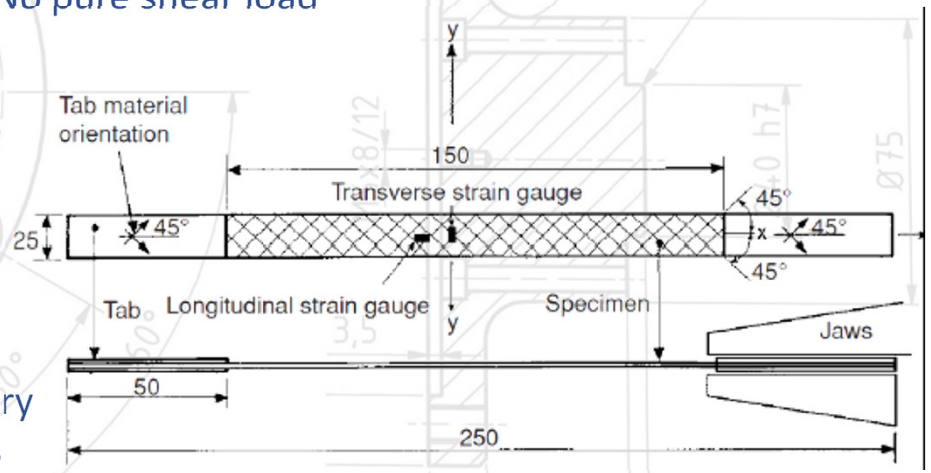
Static tests: thrust

45° tensile test

Application: Cross-Ply,
±45° balanced and symmetrical
Standard: EN ISO 14129, ASTM D3518
Similar: DIN 65466

Advantages:
Cost-effective specimen preparation
Very accurate test results
Test bench for simple tensile test
Simple experimental setup
Measurement of only 2 directions of elongation necessary
Standardised according to EN ISO 14129 or ASTM D3518

Disadvantages:
Biaxial stress state
No pure shear load



Test specimen [1]

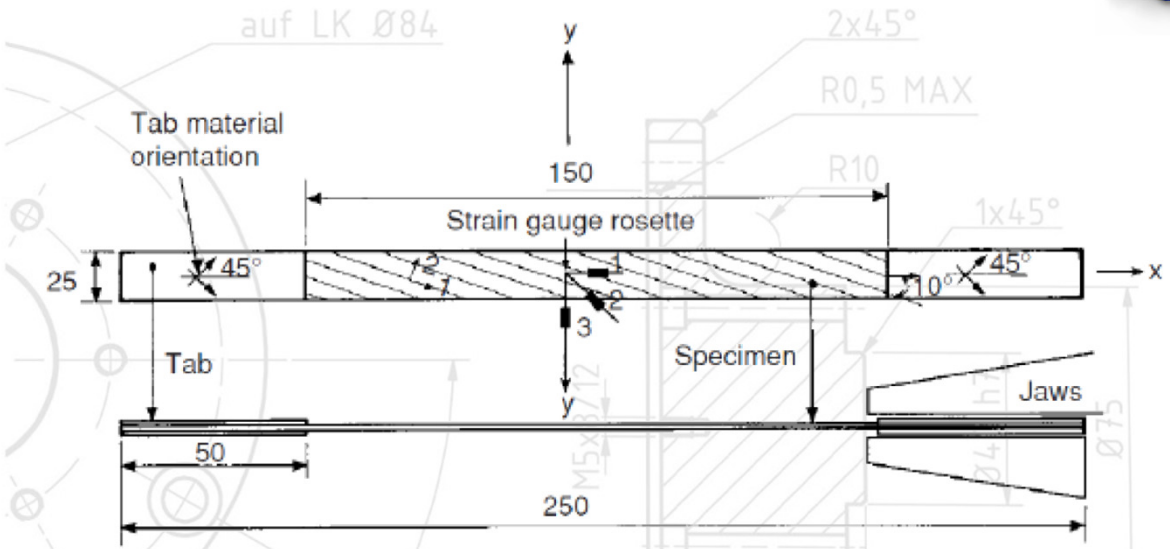
Static tests: thrust

10° tensile test

Application: UD laminate

Advantages:
Cost-effective specimen preparation
Very accurate test results
Test bench for simple tensile test
Simple experimental setup
No special specimen holder required

Disadvantages:
Biaxial stress state
Measurement of 3 directions of strain
No standardization according to ISO or ASTM, but the use of ISO 527 is possible



Test specimen [1]

No uniform specimen specification
Sensitive to bending/twisting, i.e. bending stresses in width/thickness direction < 3%.

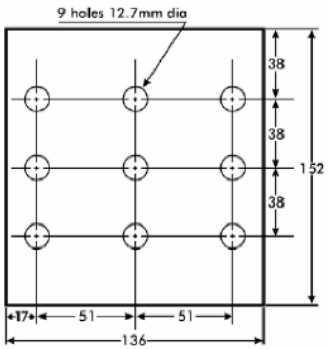
Static tests: thrust

3-Rail shear test

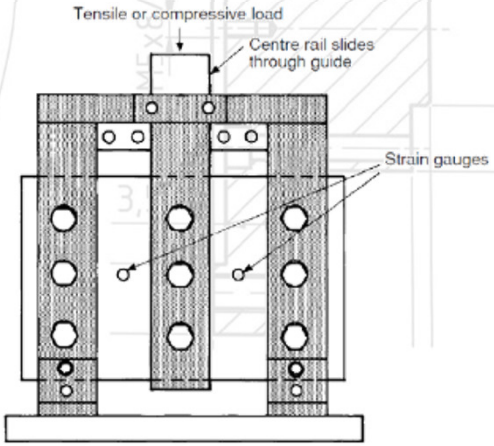
Application: UD laminate (0° or 90° to the longitudinal axis of the rails)
Standard: ASTM D4255

Advantages:
Good test results
Test bench for simple tensile/compression test
Standardization according to ASTM D4255

Disadvantages:
Large test specimen
Elaborate preparation of the test specimen (drill holes)
Complex specimen collection
High cost



Test specimen [2]



Test specimen [2]

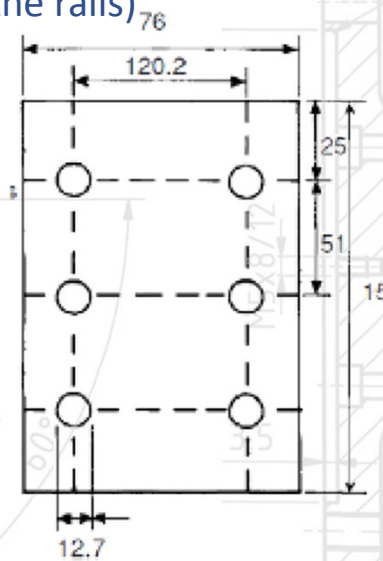
Static tests: thrust

2-Rail shear test

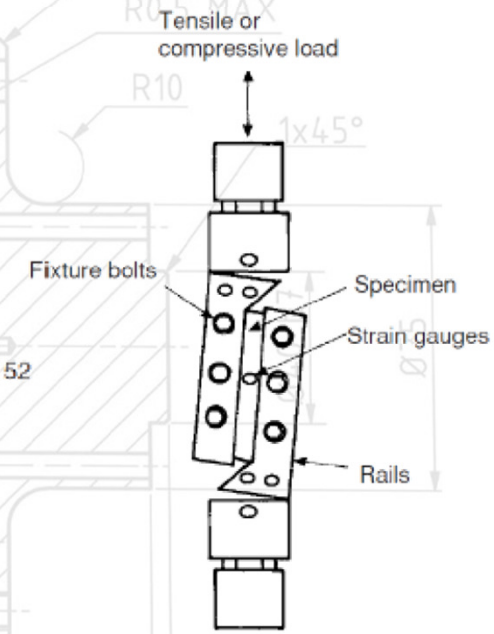
Application: UD laminate (0° or 90° to the longitudinal axis of the rails)
Standard: ASTM D4255

Advantages:
Test bench for simple tensile/compression test
Standardization according to ASTM D4255
Pure shear force applied in the area of the strain gages

Disadvantages:
Large test specimen
Elaborate preparation of the test samples (drill holes)
Complex specimen collection
High cost



Test specimen [2]



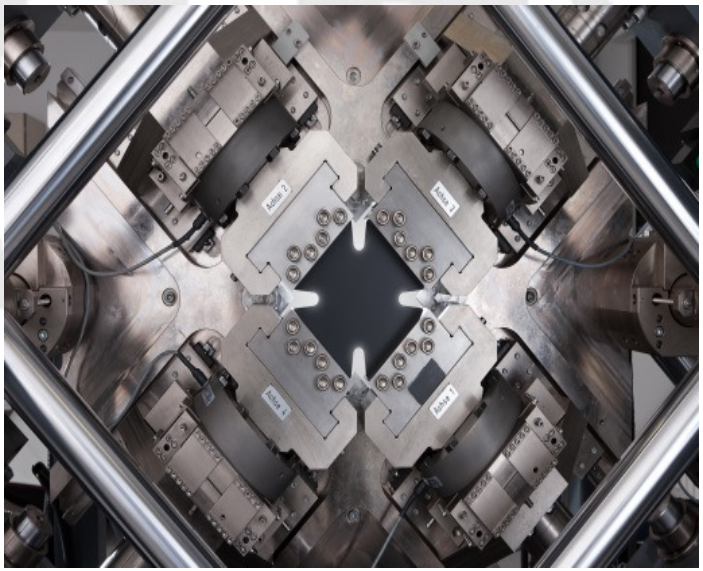
Test specimen [2]

Tests and Standards

Static tests: special tests

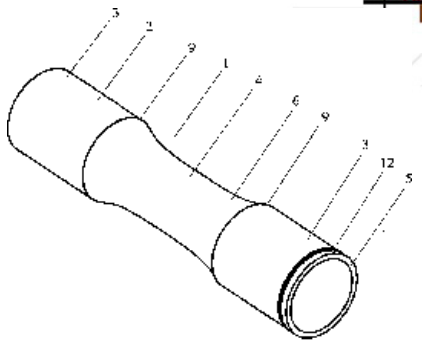
Biaxial tests for failure bodies

Biaxial tensile load

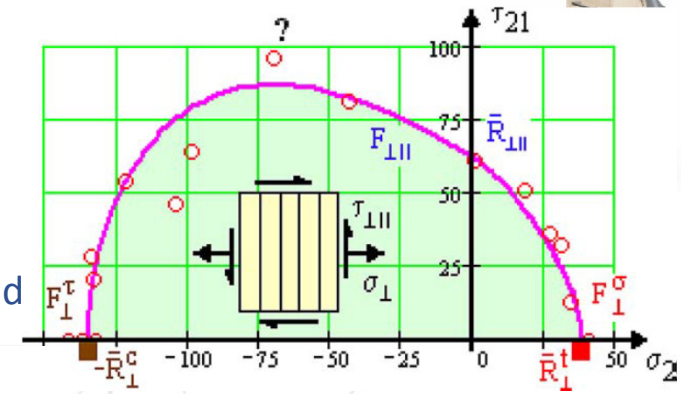


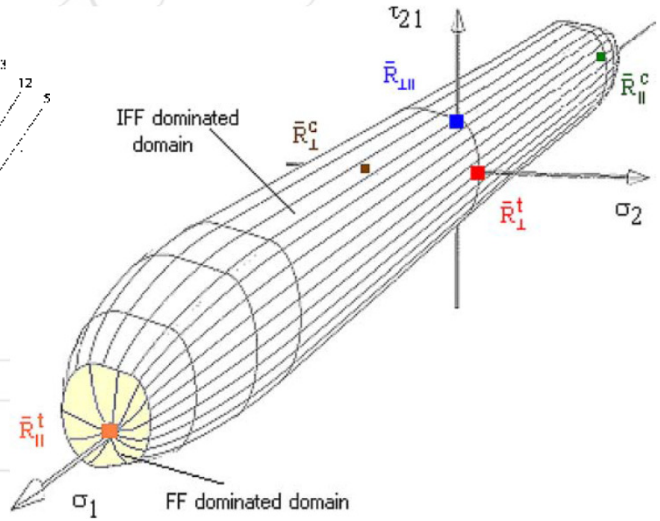
Source: [3]

Torsion/tension/compressive load



Source: [4]





2D & 3D fractured bodies according to Cuntze failure criterion [5]

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ISO 527

Section1	general guidelines
Section 2	test conditions for form and extruded materials
Section 3	test conditions for foils and tablets
Section 4	test conditions for isotrope and anisotrope fibre reinforced composites
Section 5	test conditions for unidirectional fibre reinforced composites

- For single phase plastics and blends, filled and unfilled, fibre reinforced materials, extruded and molded plastics, foils and plates, machine acc. ISO 5893
- Length measuring displayed with uncertainty better than 1%, i.e. for modulus ±1µm, i.e. with respect to ISO9513 that means resolution better than 0.5µm for Lo≥50mm
- Calibration acc. ISO7500 and ISO9513

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ISO 527
Normative changes in 2012

- Increase Lo for 1A specimen from 50 to 75mm→ benefit for Youngs modulus
- Two different possibilities of strain display
  - Nominal strain on basis of LoT $\varepsilon = \frac{\Delta Lo}{Lo}$ $\varepsilon_T = \frac{\Delta L_T}{LoT}$
  - Combined strain of ε and ε_T $\varepsilon_y = \frac{\Delta Lo}{Lo}$ $\varepsilon_T = \varepsilon_y + \frac{\Delta L_T}{LoT}$
- Detailed description of poisson ratio
- Demand on measuring frequence
- Change of speed after modulus determination allowed, but before 0.3% strain (9.6)
- Various tests can be conducted with one specimen (modulus + test to fracture)
- Definition of tolerance to specimen thickness (h_{max}-h)≤ 0.1mm
- Value of precision
- Normative appendix for computer supported determination of yielding point
- Detailed requirement to length measuring system, for calibration refer to ISO9513
- Normative appendix for calibration of length measuring system

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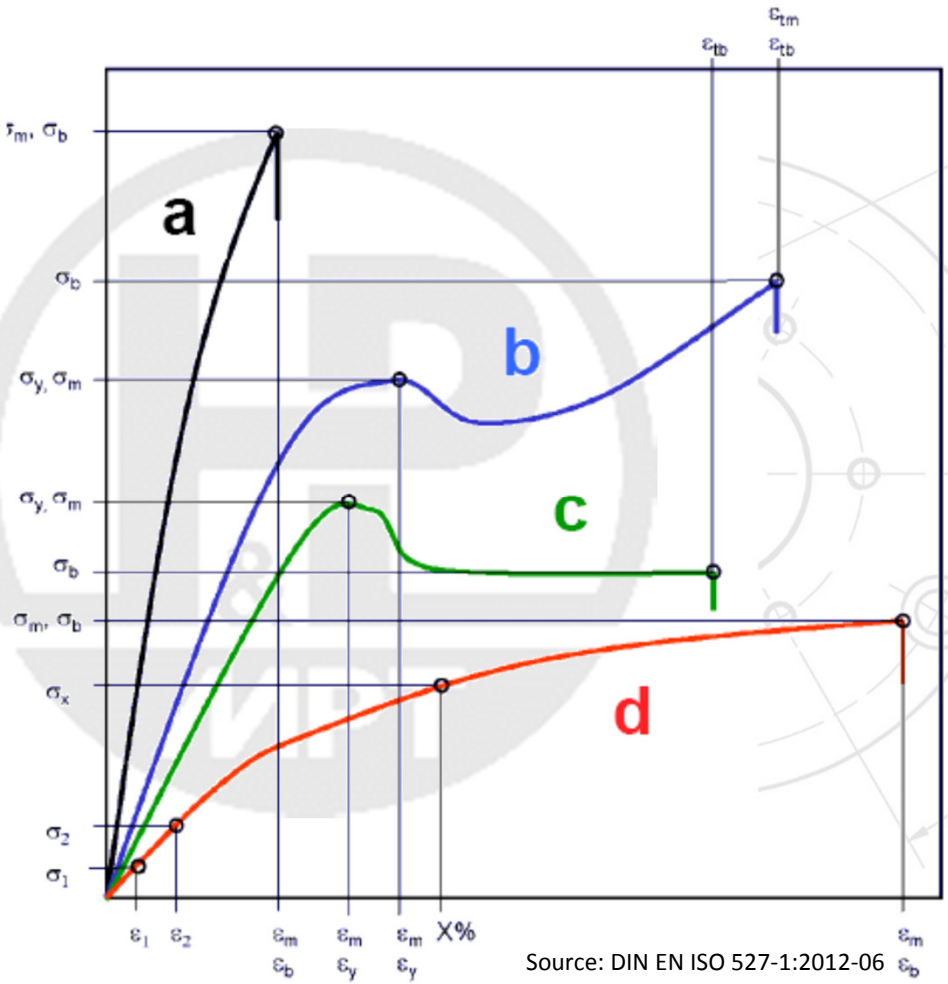
ISO 527
stress-strain graphs



Source: DIN EN ISO 527-1:2012-06

- Yield stress σy: first stress, when no stress increase at increase of strain
- Modulus between 0.05% and 0.25%
- Nominal strain: related to LoT
  ⍰ for strains beyond any yielding point
- Strain until yielding point related to Lo

a	thermosetting, brittle plastic
b/c	semicrystalline/ ductile materials
d	elastomers

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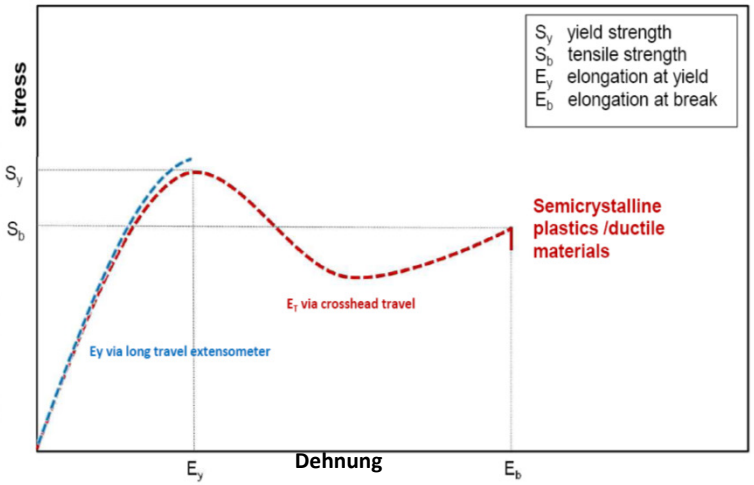
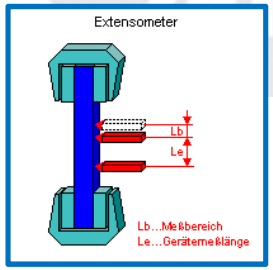
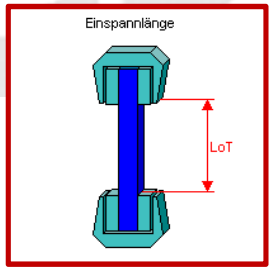
ISO 527
strain display

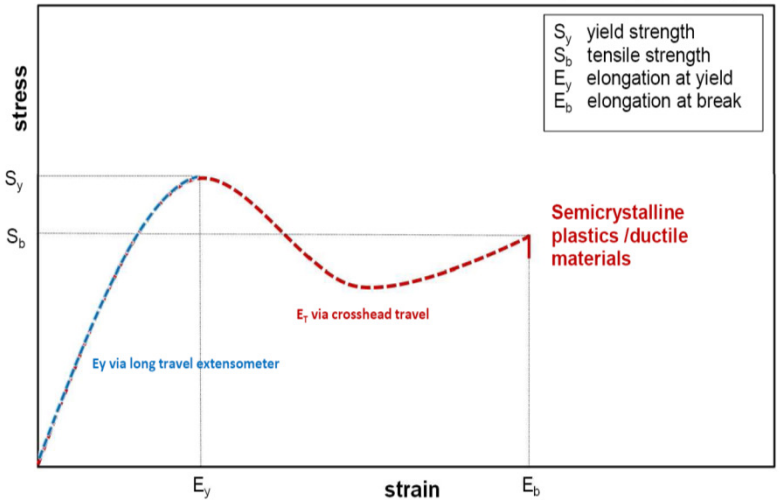
Method A
Two graphs needed to display all results







Method B
New in version 2012 – one plot



Especially with optical ext. 2-sided measurement is suggested, in any case deformation and flexural effects must be avoided

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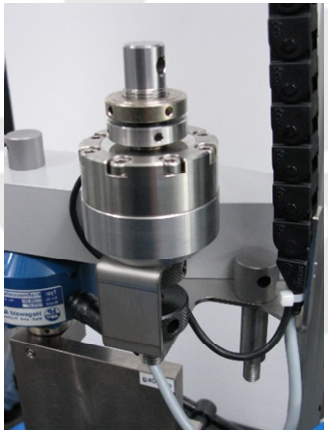
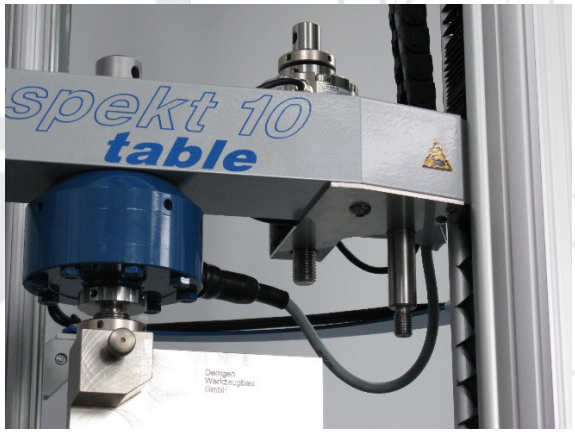
Requirements on UTM – clamping

- Plastic testing is mainly many specimen with same specimen length and shape (1A for injection moulded specimens, 1B for mechanically machined specimens) → "zero" position at optimum grip position to return after test
- "zero" load un unloaded stage prior load connection, i.e. clamping specimen on upper and lower end

  → **loads arising during clamping process do really act and are part of test**





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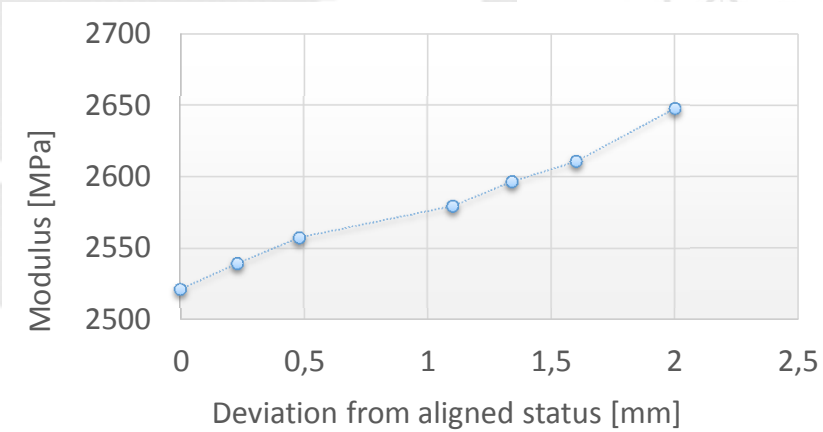
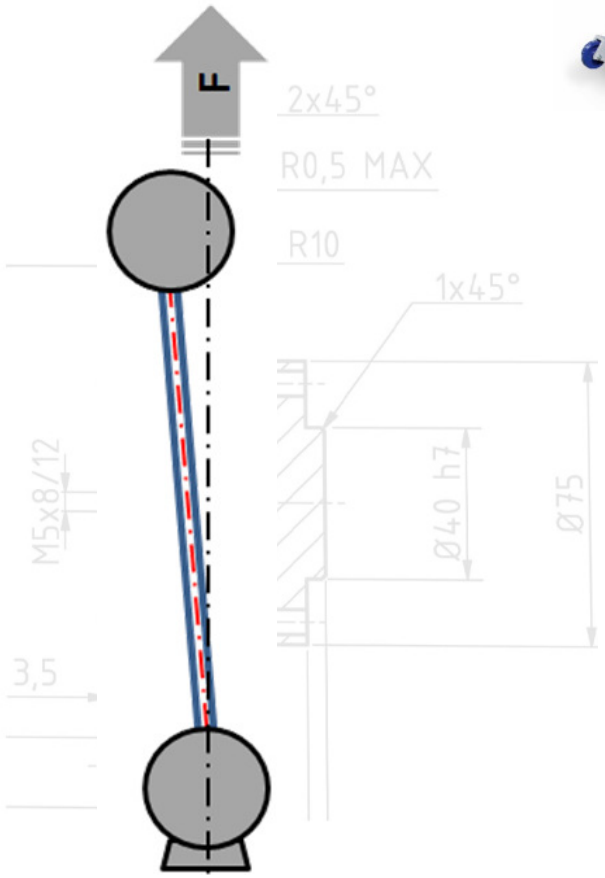
Specimen alignment

- Clamp the specimen straight, centered and aligned in load axis
  - to avoid flexural forces
  - To avoid problems at measuring tensile modulus
  - → Depending on material deviations of 5% are known caused by only 2mm disalignment of specimen





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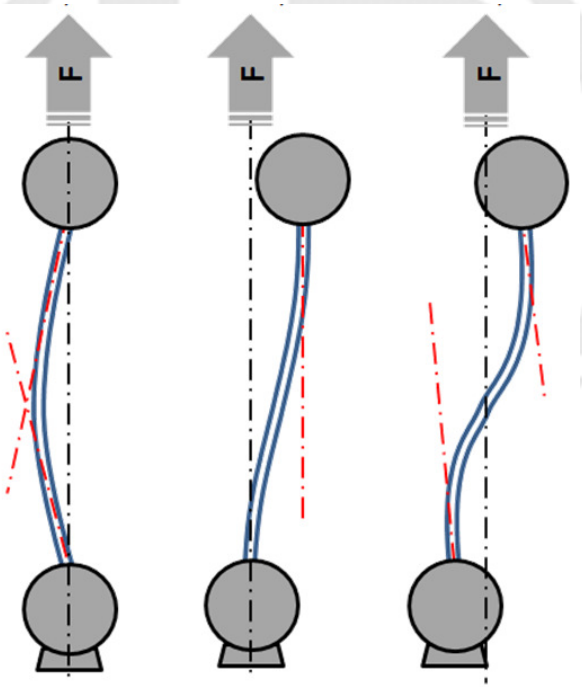
Holdmode

- Try to avoid pre tensioning and shear stresses during clamping process to ensure to measure intrinsic material properties

→ Utilize „Holdmode active“ closing lower grip to ensure load remains constant during clamping process



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Pre-load

- Attention at setting the pre-load!
- Yes, a small pre-load avoids a tail at beginning of test, especially working with pincer and wedge type grips
- However, the preload is per definition the start of test and accords to „zero“ strain – though a clear start point is defined and results might be comparable independent from user and machine and it‘s configuration.
- The pre-stress should be set below 0.05% strain of the material,

Remember the youngs modulus is determined between 0.05% and 0.25%

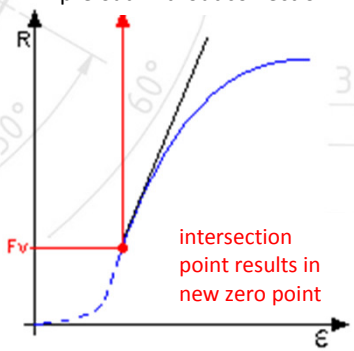
- For determining the relevant stress employ

→ Setting the pre-stress to small LabMaster offers the possibility to re-calculate the test increasing the pre-stress

→ Beyond you can employ the pre-stress correction

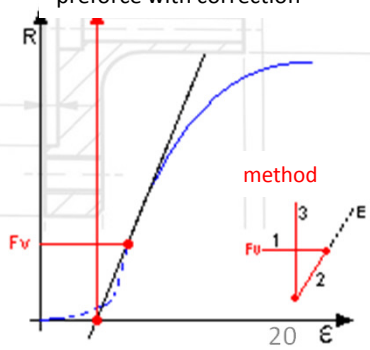
$\sigma_0 \leq \sigma / 100$

preload without correction



$\sigma_0 \leq E_t / 2000$

preforce with correction



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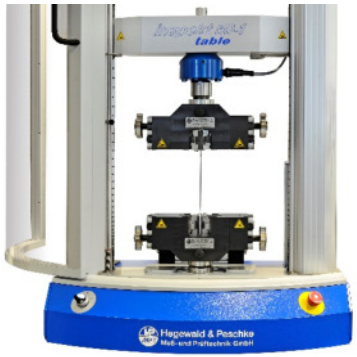
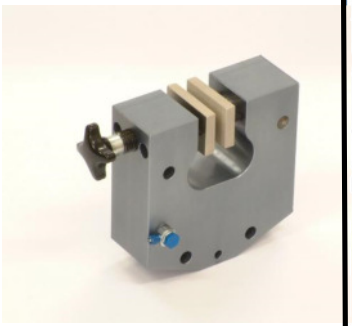
Young's Modulus determination I

- Parallel grips support precise speed control
- A strain control rate of approx. 1% of the measuring length /min is suggested for modulus determination, whereby a speed from table 1 in ISO527-1 needs to be utilized
- 1 mm/min crosshead speed accords to 0.87%/min for 1A and 1B specimen
- The use of wedge type grips results in too low and wedge action grips at variable speeds; parallel closing grips are optimal.

V to small



V unstable



optimum

Table 1 – recommended test speed

test speed v mm/min	limiting deviation %
0,125 0,25 0,5 1 2 5 10	± 20
20 50 100 200 300 500	± 10

Source: DIN EN ISO 527-1:2012-06

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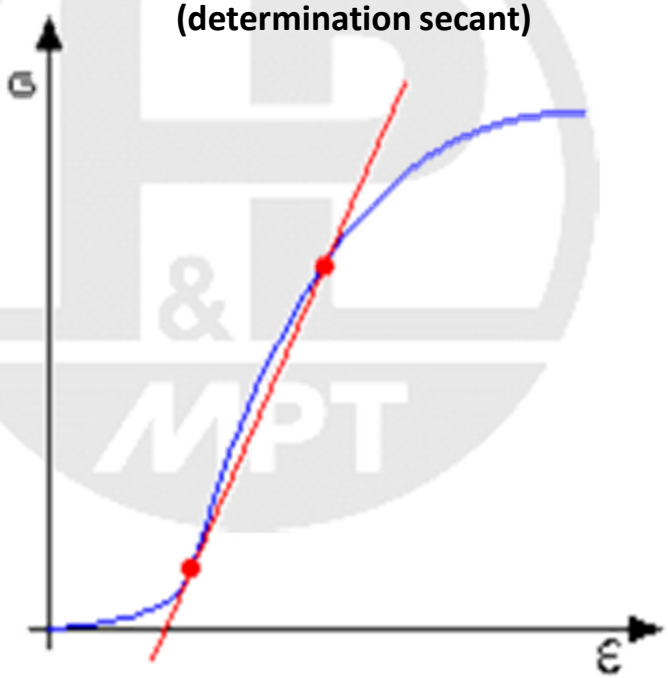
Young's Modulus determination between 0.05% and 0.25% strain

Secant calculation

Easy to apply manually,
but statistically sensitive, signal noise

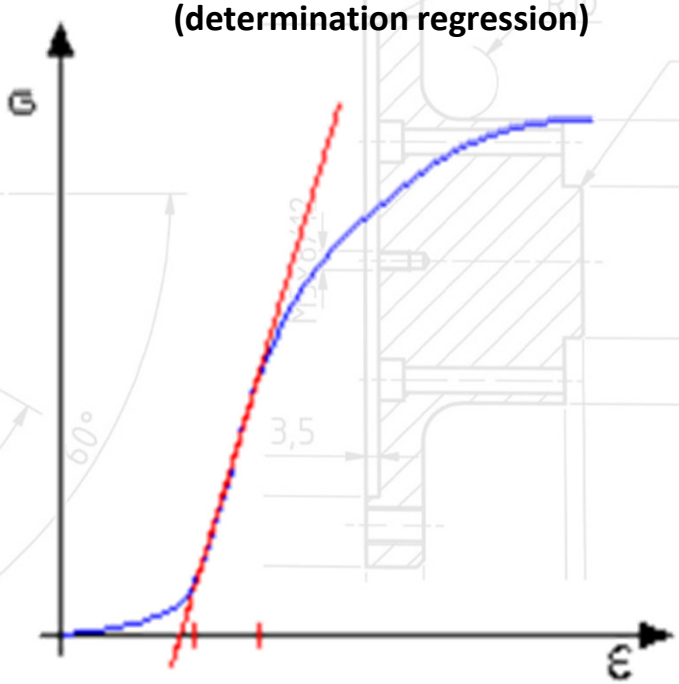
Young's modulus (determination secant)



Regression calculation

All measurement points are considered, statistically safer

Young's modulus (determination regression)



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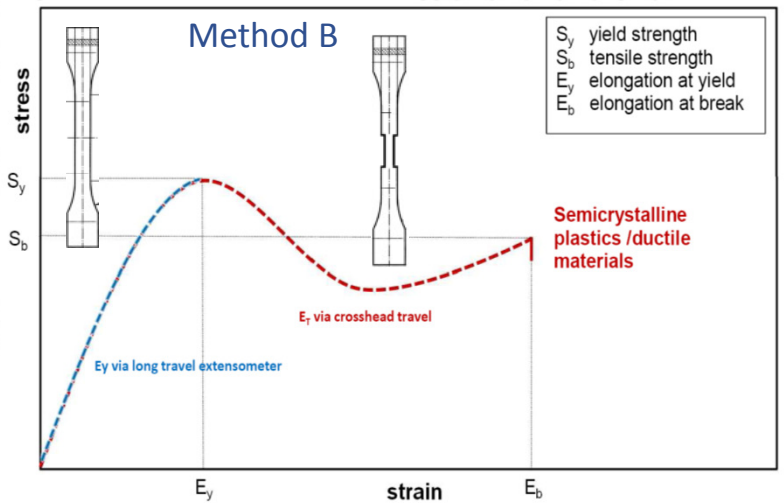
Requirements Strain measurement, test machine speed and their changeover

- ➔ After the Young's modulus measurement, the speed is switched over.
- ➔ The module and other results may be determined on the same specimen. The speed changeover must be carried out for elongations ≤0,3%.
- ➔ The speed can be switched directly after the module determination. However, it is preferable to relieve the specimen after the module determination before the speed changeover.

- ➔ Unfilled thermoplastics usually show a stretching point εy and form flow fronts accordingly: After the yield point, the strain rate increases within the flow fronts, while it can drop outside. As a result, the direct strain measurement after the yield point is usually statistically uncertain.



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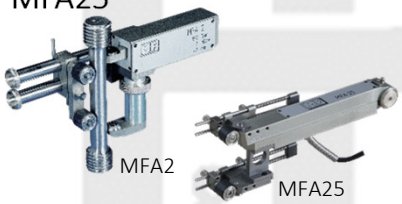
Extensometers

E-modulus measurement requires high accuracy of strain transducers; i.e. ±1.5 µm for Type 1A with Lo 75mm and ±1.0 µm for Type 1B with Lo 50mm. For smaller specimens (Lo 25mm 0.5µm) higher accuracies are required.

clip-on extensometer

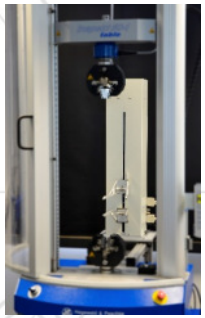
MFA2 /mini
MFA25



- cost efficient
- preferably for determination of elastic properties
- longitudinal / transversal
- limited in measuring range

long travel extensometer

L1100
MFE 910
MFX 200/500
MFL 300



- depending on instrument useable for determination of strain for wide range of materials up to fracture
- fully automated available, suitable for automated systems
- recommended for strain controlled testing

video

- marking necessary
- suitable for various (sensitive) materials at high- and low temperatures
- no abrasion, suitable for measurement until fracture
- quality depends on optical outer influences
- transversal/axial

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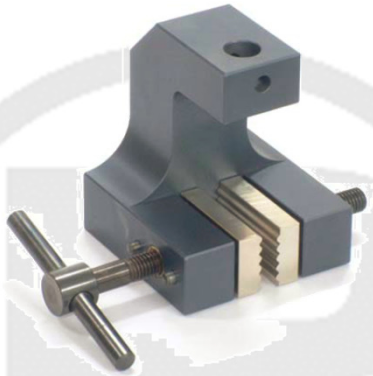
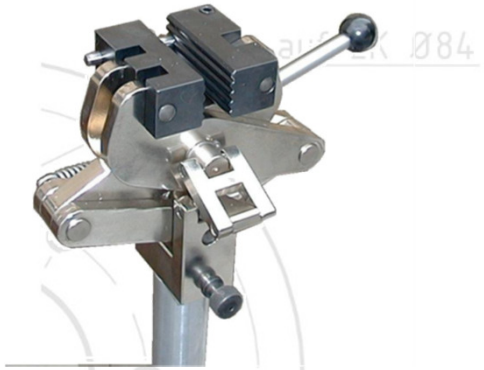
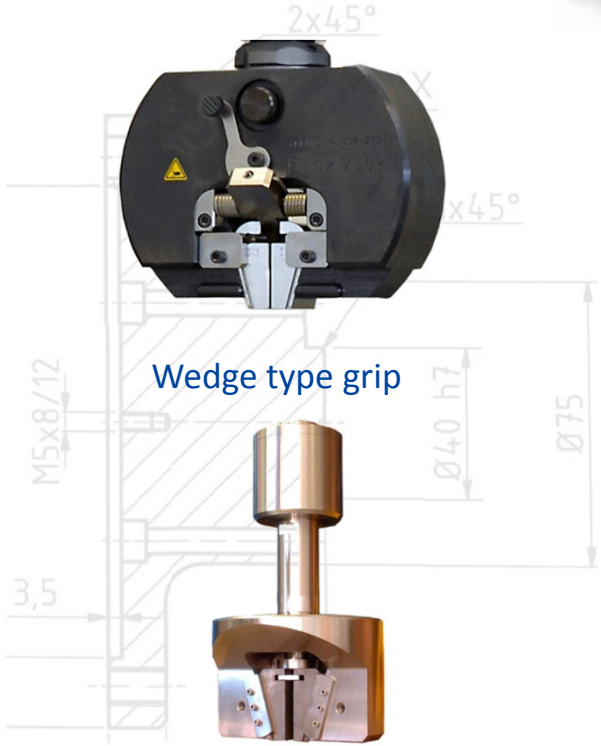
Grips for RT & chamber application



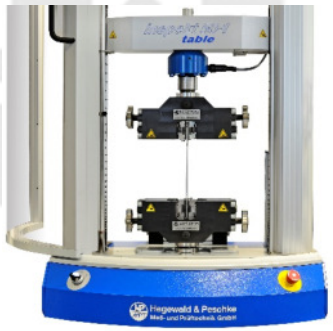
Vice grip



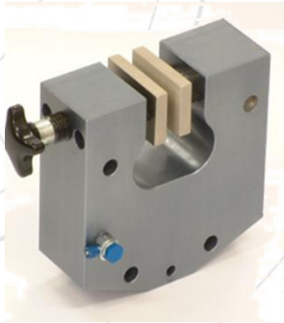
Scissor grip



Wedge type grip



Wedge action grips



Pneu. parallel grip

Hydr. /pneu.
wedge grip

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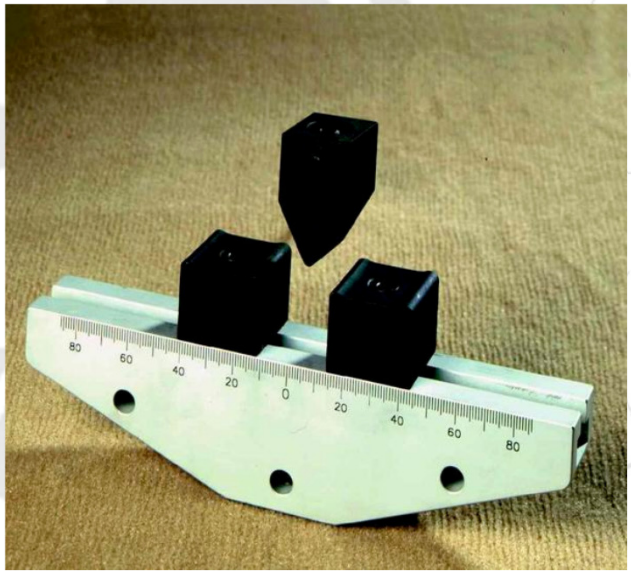
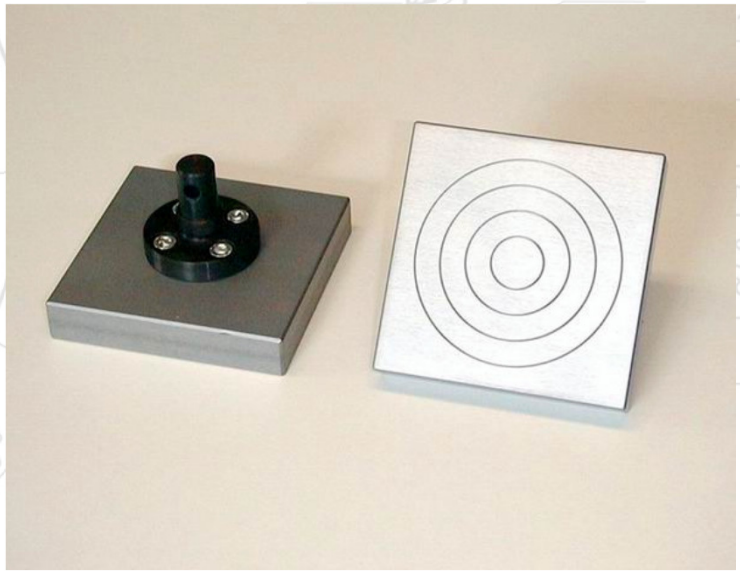
Further Grips

Flexural test acc. ISO178
Span 10-100mm
Support R2 / R5 mm
Stamp R5 mm



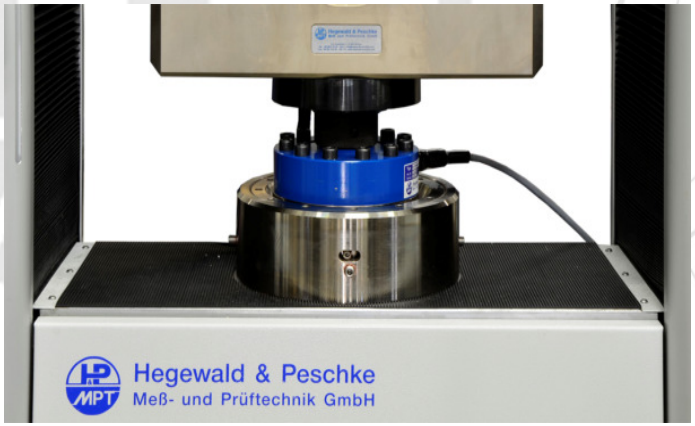
Compression plates
Squared (250 mm) or
Round (ø 56 / 96 mm)

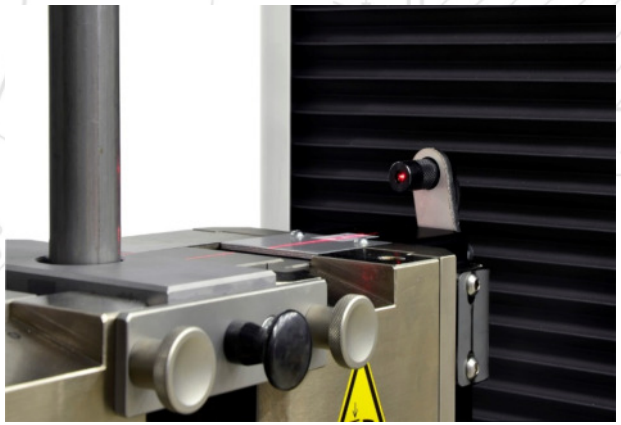


Fibre reinforced composites:

- anisotropic material with high degree of stiffness and rigidity and brittle fracture characteristic require stringent requirements with regard to the quality of drive and guide components, axiality, backlash and stiffness

→ Demand on high precision in:
Fixtures and gripping
load transmission, i.e. centricity achieved by means of special alignment fixtures
accuracy of extension measurement





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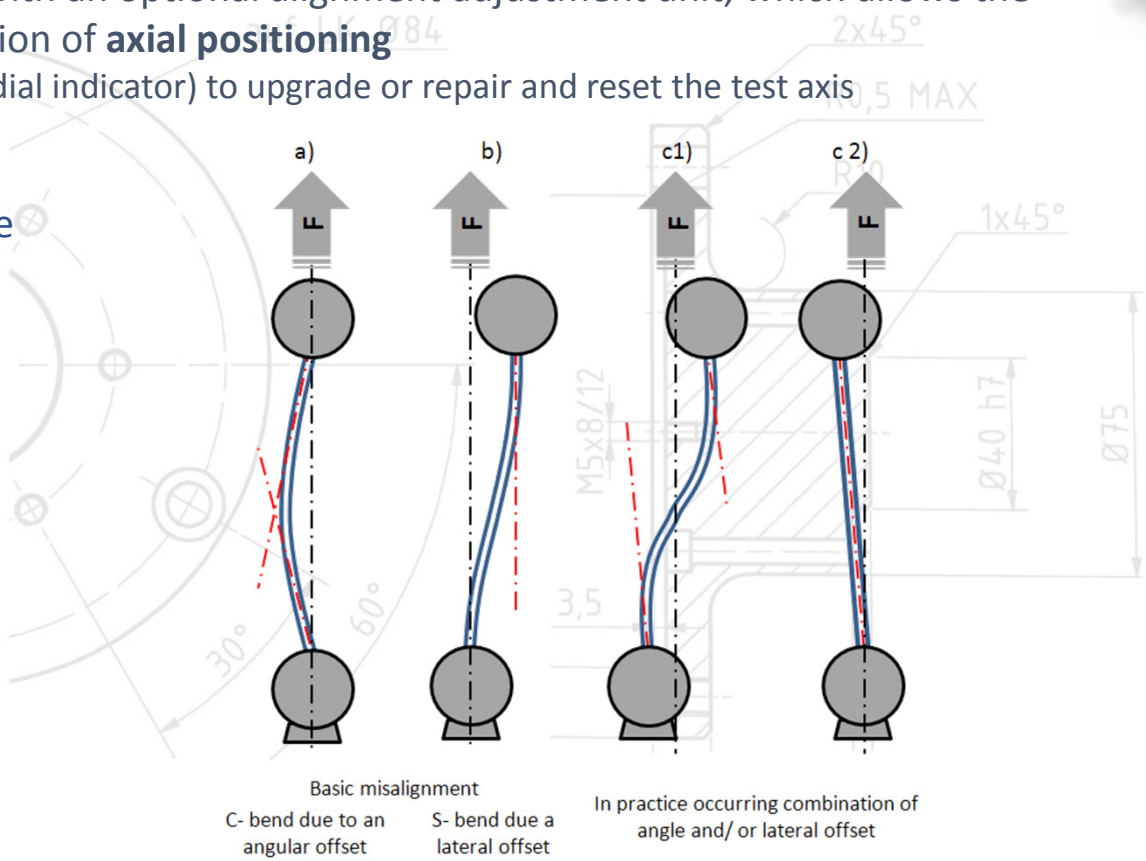
Composite Testing – Alignment

All H&P testing machines can be supplied with an optional alignment adjustment unit, which allows the variation of **angular position** and optimization of **axial positioning**

→ Together with the alignment unit is a gauge (dial indicator) to upgrade or repair and reset the test axis

- verification and readjustment according to ISO23788/ ASTM E1012 (NADCAP) are offered with Strain-Gauged Specimens
- Axial offset correction of load cell and adaption and fixture possible
- NASM 1312 local alignment calibration



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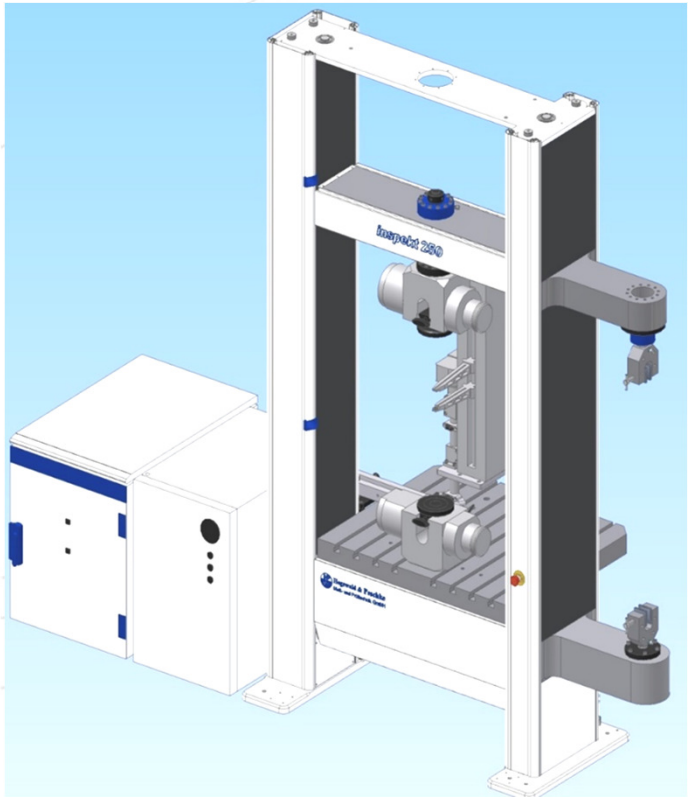
Composite Testing
Inspekt 250/50

Inspekt 250/50kN

stiffness 260 kN/mm

1 test room width: 610 mm
2 test room depth: 150/300 mm (in relation to test axis)

- test room height: 1680 mm
- crosshead speed range: 0.002 - 450 mm/min
- 1000Hz data acquisition rate / 5kHz sampling rate



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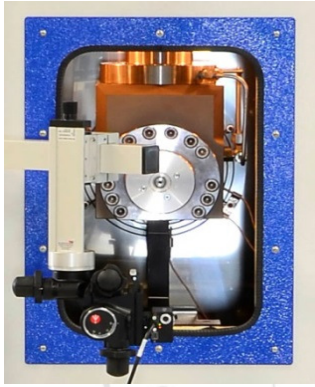
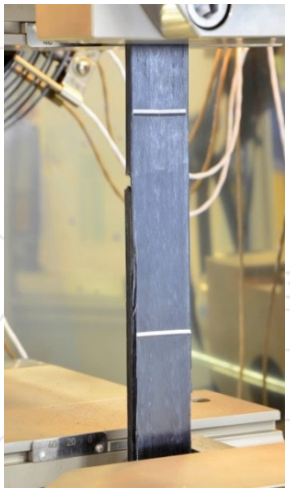
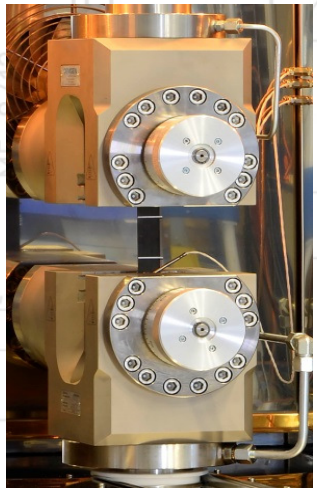
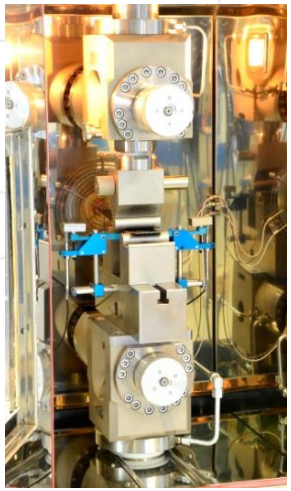
Composite Testing in TC



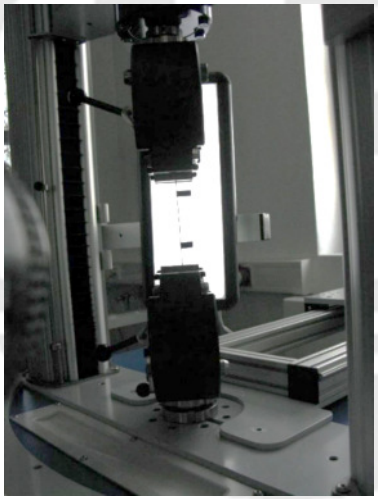
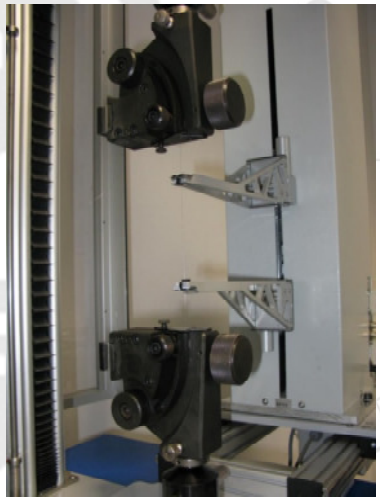
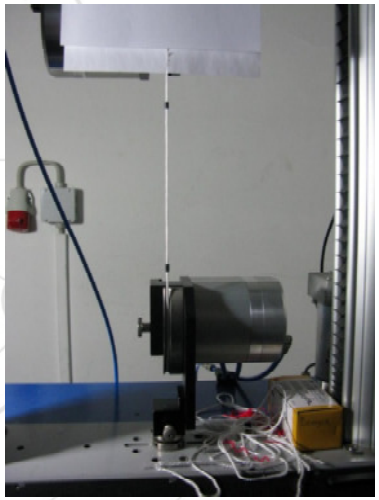
- UTM Inspekt 250kN with temperature chamber (-70…+350°C), video extensometer, hydraulic grips and bending fixture with displacement sensor for application inside the chamber







GRIP: depending on material, thickness/diameter and strength

Wedge type grip - saw teeth	Bollard grip	Pneu./hydr. bollard grip
		

Rm 4900 MPa, d 0,11 mm

EXTENSOMETER: Video or long travel extensometer?

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Plastic Tensile Testing

- Determination of Youngs modulus and strain at fracture, strains up to 1000%
- Two-camera system with an optical window for evaluation until fracture and small strain parameter evaluation

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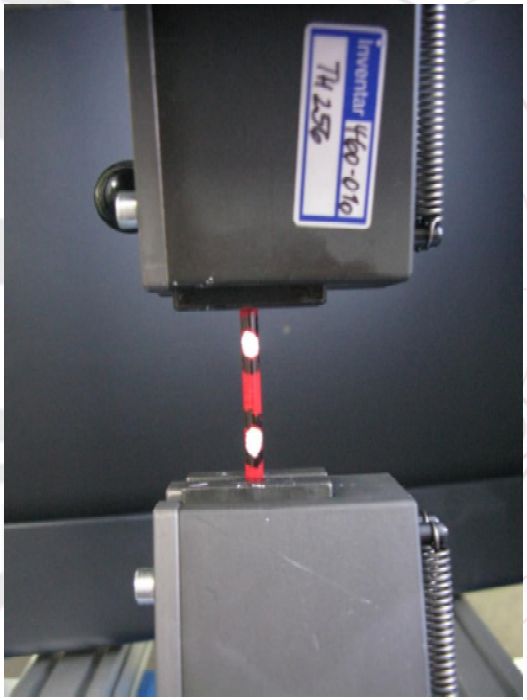
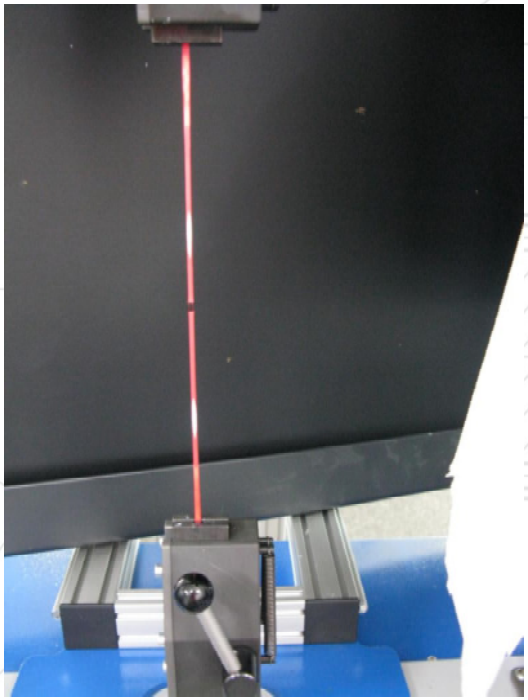
Plastic Tensile Testing with Videoextensometer





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Elastomer testing with Video extensometer
F_{max} 100N, strain >1000%

- Determination of tensile modulus and elongation at rupture, elongation up to 1000 %.
- Two-camera system with one optical window for evaluation up to break and parameter evaluation at low elongation
- Additional pneumatic specimen holder
- Designed for tests within temperature chambers

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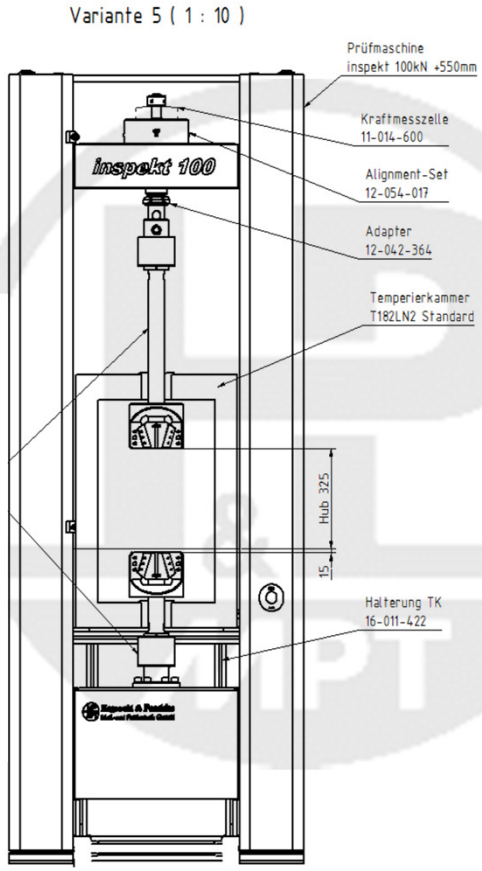
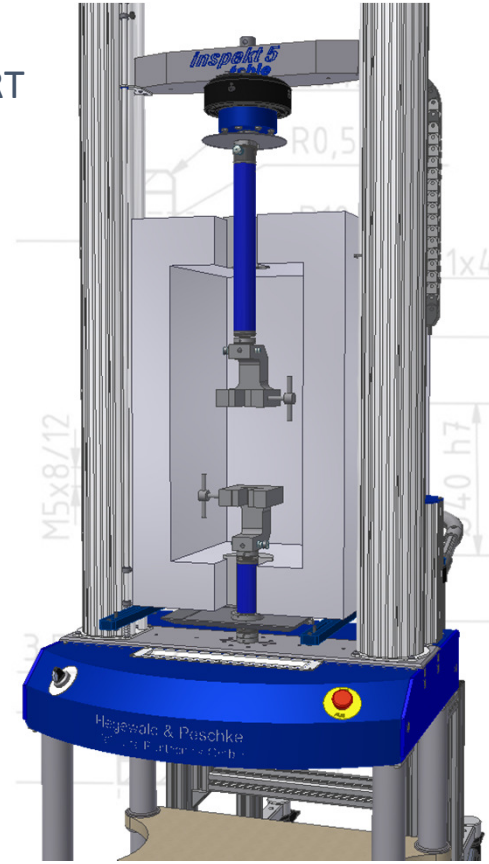
Temperature application



- → Temperature or climatic chamber
- → Which tests in chamber and which at RT
- → Specimen material
- → Specimen dimension
- → Lo
- → Expected strain inside chamber

Stroke limitation by machine height
Stroke limitation by chamber
Pullrod length



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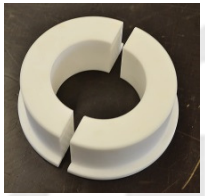
Chamber parts

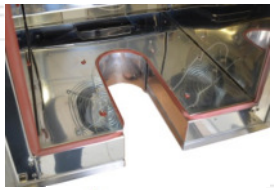


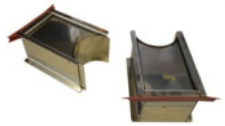
Equalizing rings – insulation of bushings of load transmission

Control with Eurotherm control and RS485

- Eurotherm-module
- overheat protection
- three thermo couple (1 overload protection, 1 environment, 1 specimen)

Thermo glas window, optical window (antireflective)





Shelfs for running in/out the chamber keeping load transmission

Ventilation with environmental thermo sensor

Chamber lighting

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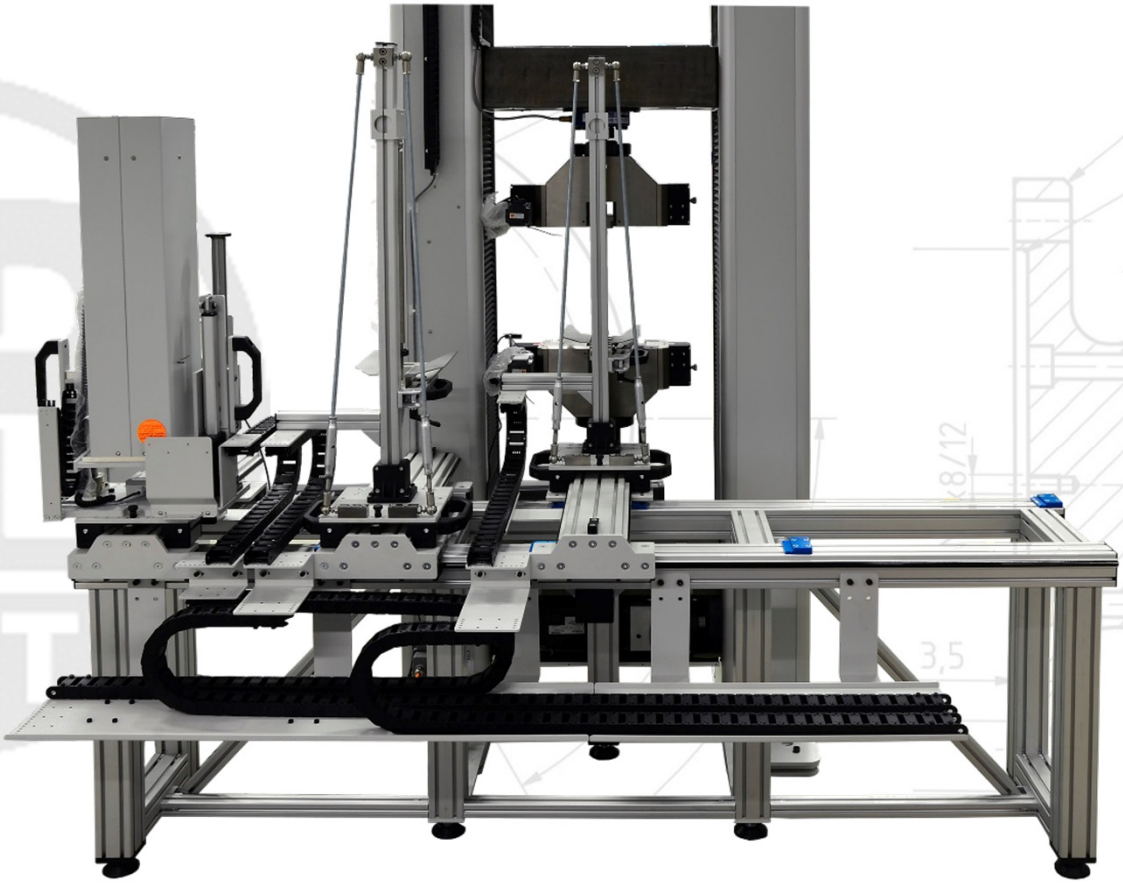
Chamber carrier systems



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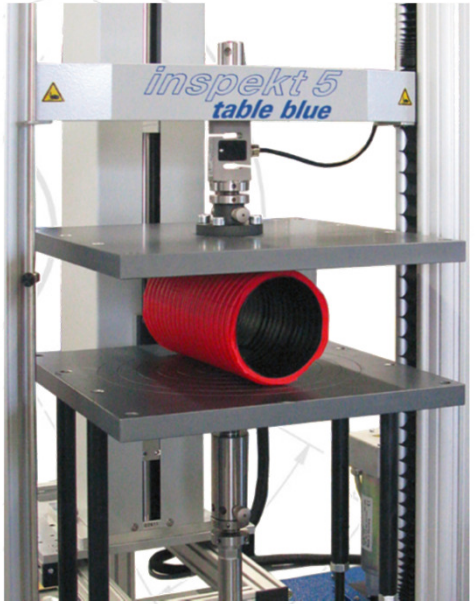
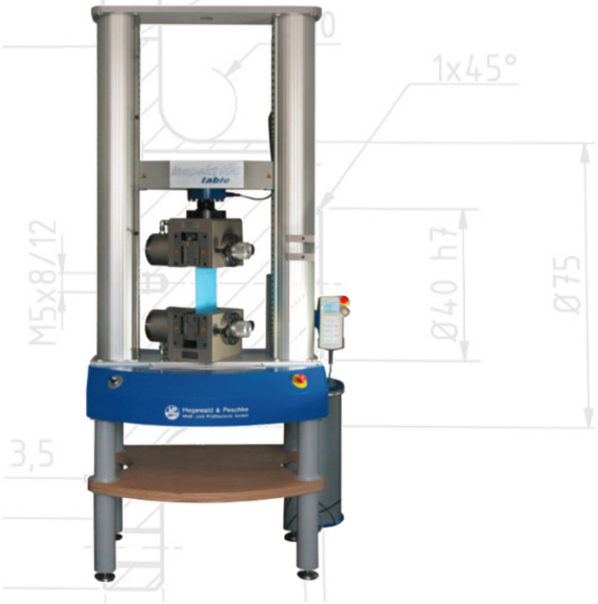
Applications

(bio-)medical

apex pressure on pipes



geotextiles



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Sources

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[2] Adams D. F.; Carlsson L.A.; Pipes R. B.: Experimental Characterization of Advanced Composite Materials. 3rd Edition, CRC Press, Boca Raton, 2003

[3] Fraunhofer Institut für Werkzeugmaschinen und Umformtechnik

[4] Patent DE 202012008324 U1: Rohrprobe zur mechanischen Prüfung und zur Ermittlung der einen zu prüfenden Werkstoff charakterisierenden Belastungswerte und Eigenschaften

[5] Cuntze: Efficient 3D and 2D failure conditions for UD laminae and their application within the verification of the laminate design, 2006, Composites Science and Technology