Plastics - Determination of tensile properties

The 2019 version of ISO 527 -1

ZwickRoell

Agenda

1. **History and scope**
   Parts of ISO 527
   Significance and use
   Last modifications in ISO 527-1

2. **Test specimen**

3. **The tensile test**

4. **Comparable materials data**

5. **Requirements to the equipment**

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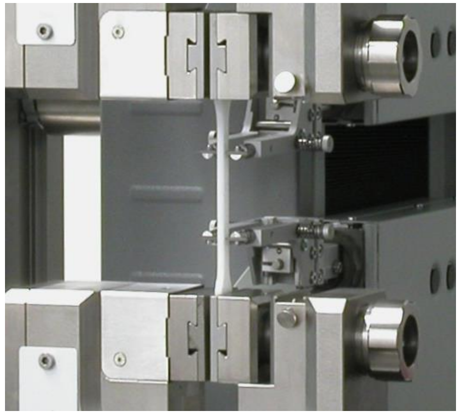
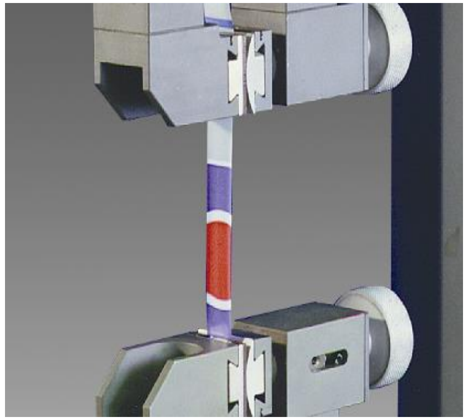
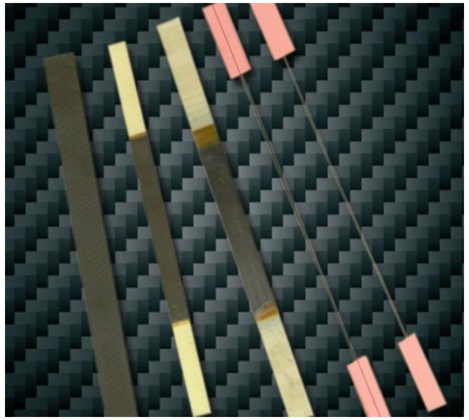


ISO 527, part 2



ISO 527, part 3

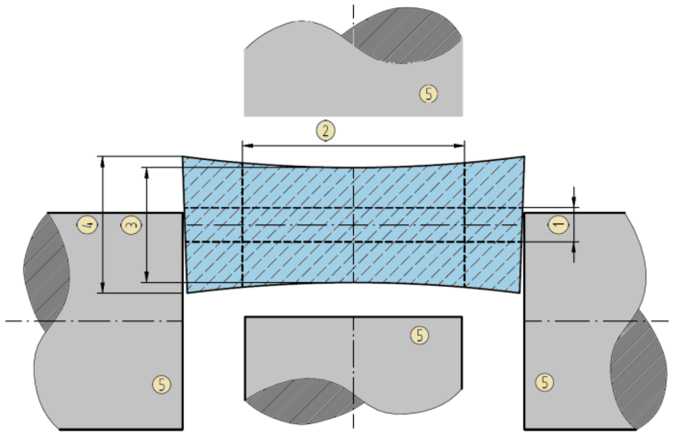


ISO 527, parts 4 & 5

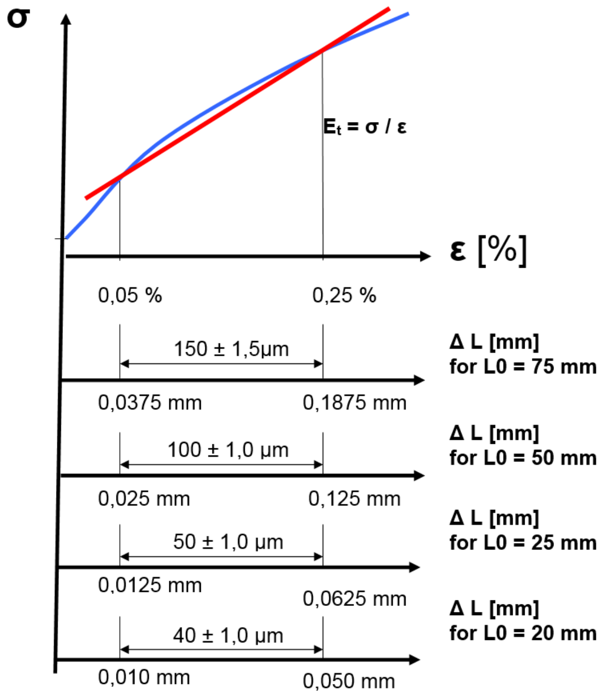
ISO 527 is a family of standards covering tensile tests on plastics and composites

- Part 1: General principles
- Part 2: Test conditions for molding and extrusion plastics
- Part 3: Test conditions for films and sheets
- Part 4: Test conditions for isotropic and orthotropic fiber-reinforced plastic composites
- Part 5: Test conditions for unidirectional fiber-reinforced plastic composites

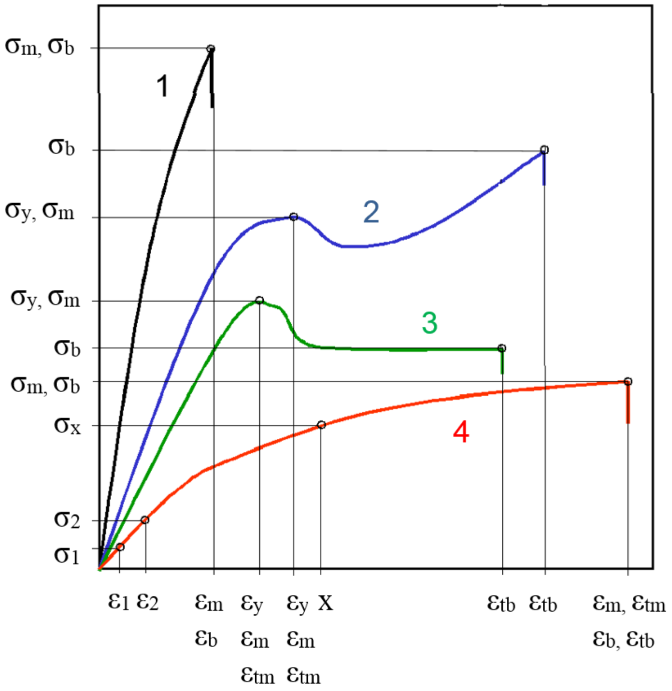
Three major amendments have been applied by the last revision in 2019



Introduction of clear definitions and requirements on cross sectional measurements



Requirements for extension measurement for tensile modulus determinations have been re-defined in figure 2



New definitions for strain results at max stress and at break

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The ongoing revision of ISO 527-2 aims to harmonize the specimen definitions with ISO 20753 – test specimen

Table 1 — Test specimen dimension and test dimension for type A1 and A2 acc. ISO 20753

Dimensions in millir

	Test specimen dimension	A1	A2
l_3	Overall length	See ISO 20753	See ISO 20753
l_2	Distance between broad parallel-sided portions	See ISO 20753	See ISO 20753
l_1	Length of narrow parallel-sided portion	See ISO 20753	See ISO 20753
r	Radius	See ISO 20753	See ISO 20753
b_2	Width at ends	See ISO 20753	
b_1	Width at narrow portion	See ISO 20753	
h	Preferred thickness	See ISO 20753	
	Test dimension	**A1**	**A2**
L_0	Gauge length (preferred)	75,0 ± 0,5	50,0 ± 0,5
	Gauge length (acceptable if required for quality control or when specified)	50,0 ± 0,5	
L	Initial distance between grips	115 ± 1	115 ± 1

Table 3 — Dimensions of type A1 and type A2 test specimens

Dimensions in millimeters

	Dimension	Type A1 multipurpose (injection moulded)	Type A2 (mashined)
l_3	Overall length[a]	≥ 150	
l_2	Distance between broad parallel-sided sections[b]	109,0 ± 4,0	
l_1	Length of narrow parallel-sided section	80,0 ± 2,0 [c]	60,0 ± 2,0 [c]
r	Radius of shoulder	24,0 ± 1,0	60,0 ± 1,0
b_2	Width at ends	20,0 ± 0,2	
b_1	Width of narrow parallel-sided section	10,0 ± 0,2	
h	Thickness (preferred)	4,0 ± 0,2	

[a] In case of injection molding in accordance with ISO 294-1 and ISO 10724-1 the recommended overall length should be 170 mm for the type A1 test specimen. For some materials, the length of the tabs may need to be extended (e. g. l_3 = 200 mm) to prevent breakage or slippage in the jaws of the test machine.

[b] Resulting from l_1, r, b_2, b_1, but within the indicated tolerance limits, calculated by $l_2 = l_1+[4r(b_2-b_1)-(b_2-b_1)^2]^{1/2}$ (reference: ISO 527-2:2012 Table 1, note b).

[c] All tolerances for l_1, b_2, b_1, h of A1 and A2 identical with tolerances for types B, D, F.

Proposal ISO/CD 527-2

contains only the test related information, such as gauge length and initial distance between grips. All specimen related information is given in ISO 20753.

The new designation of specimen will be in accordance with ISO 20753. Specimen 1A → A1; 1B → A2; 1BA → A22, 1BB → A25

ISO 20753

Replaced the former definition of multi-purpose specimen (ISO 3167)

Furthermore contains scaled down test specimen by ratios of 1:2, 1:3, 1:4, 1:5, 1:8, different types of platens and small tensile specimen

Contains a structured denomination system

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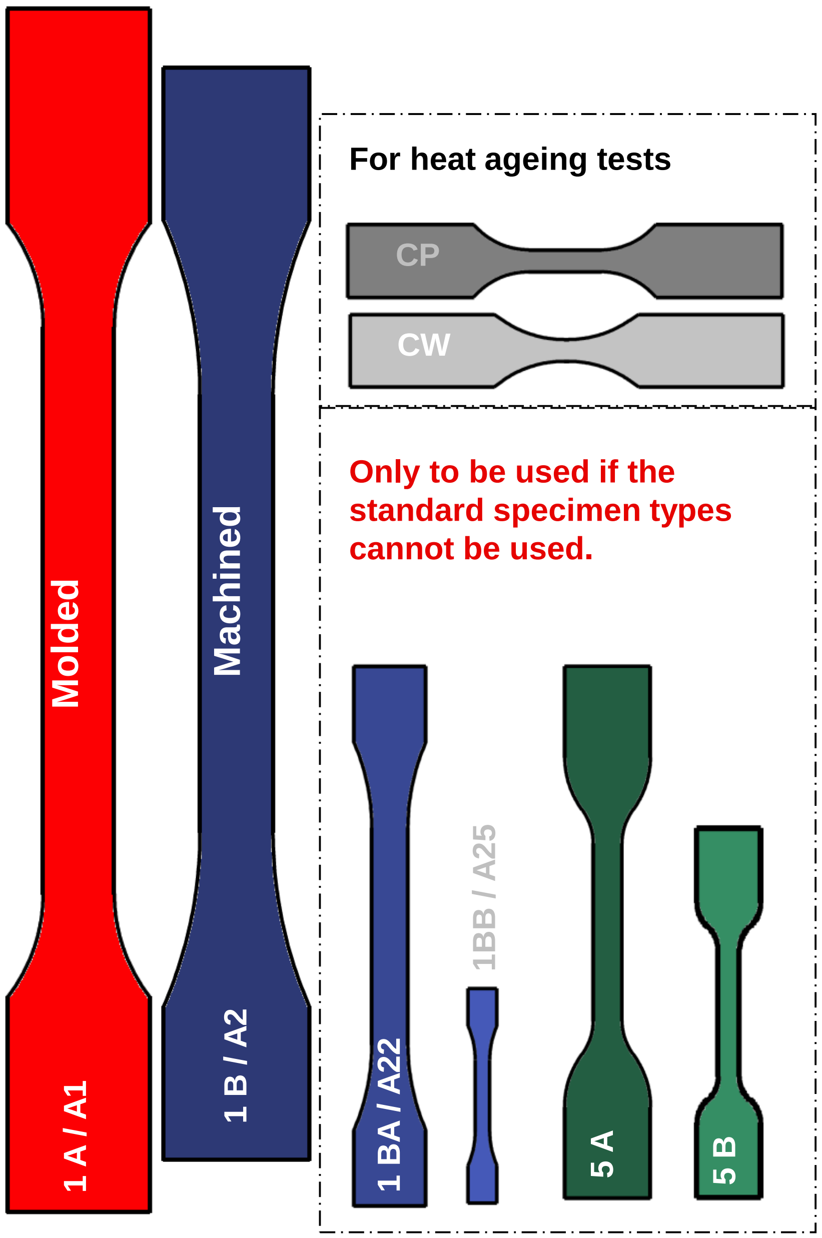


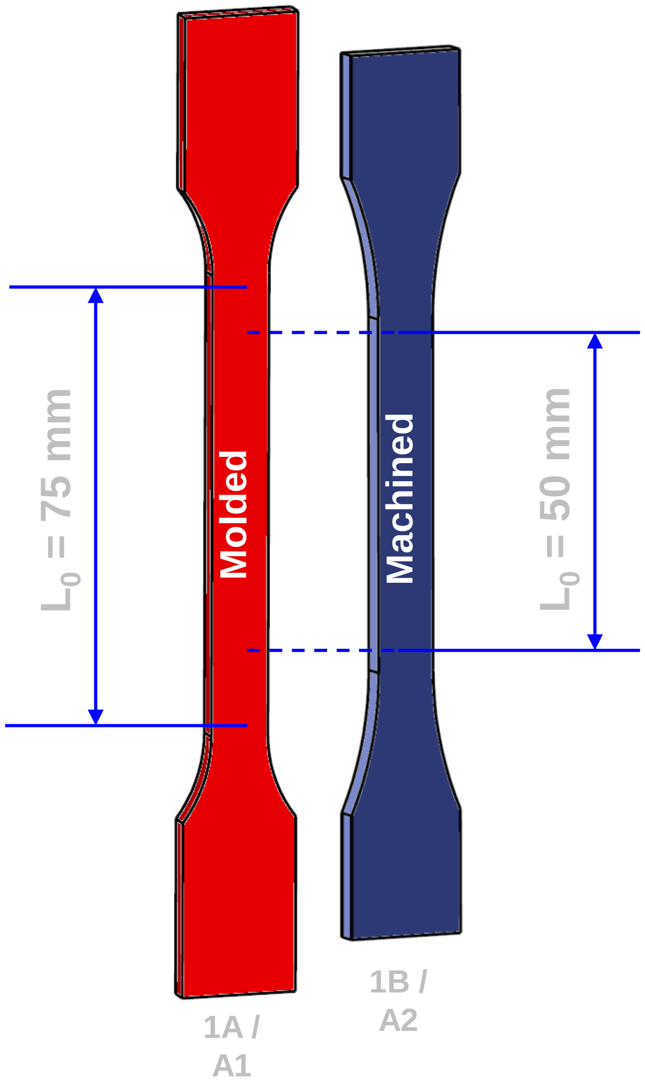
Specimen shapes & dimensions

ISO 527-2 defines specimen for molding materials

- ISO 20753 defines specimen for testing plastics
- ISO 527-2 defines specimen to be used for tensile tests
- Types 1A (A1) and 1B (A2) are standard specimen for comparable data
- Types 1BA (A22) and 1BB (A25) for reduced-scale specimen (only informative annex)
- Types 5A and 5B which are proportional to ISO 37, types 2 and 3 (only informative annex)
- Types CW and CP (identical to types 2 and 4 from ISO 8256) as small tensile specimen for heat ageing tests
- ISO 293 and 294 define conditions for compression molding and injection molding of specimen.
- Specific conditions and specimen shapes may occur in national or international materials specification standards.

Specimen shapes & dimensions

The preferred gage length for specimen type 1A is 75 mm



- Improved accuracy for modulus measurements
- No influence on yield-point determination
- No significant influence on break-point determination
- Better use of the parallel portion of the 1A specimen which is 80 mm long

- But, no change for specimen type 1B !
- Gage length of 50 mm is still allowed, but not preferred for type 1A

Accurate, standard conforming dimension measurement is needed to obtain accurate results.


ZwickRoell cross-section measurement station (CSM)

Standard micrometer with ratchet

- ISO 16012 applies for plastics, ISO 23529 for rubber.
- Plastic specimen width can be measured either by a caliper, by a micrometer or a cross-section measurement station.
- Plastic specimen thickness can be measured by a micrometer or a cross-section measurement station.
- The contact force is between 5 an 15 N, the measuring face and anvil is circular flat and typically 6.35 mm (6.5 mm) in diameter. But other shapes and dimensions are possible.
- The measurement has to be taken in the middle of the specimen and within the gage length. Injection molded specimen are measured within 5 mm around the center of the gage length.
- An error of 0.1 mm in thickness measurement corresponds to an error of 2.5 % !

Table 1 — Accuracy requirements

Dimensions in millimetres

Range of dimensions	Required accuracy
< 10	± 0,02
⩾ 10	± 0,1

Requirements of ISO 16012

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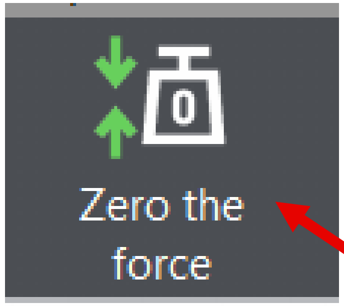
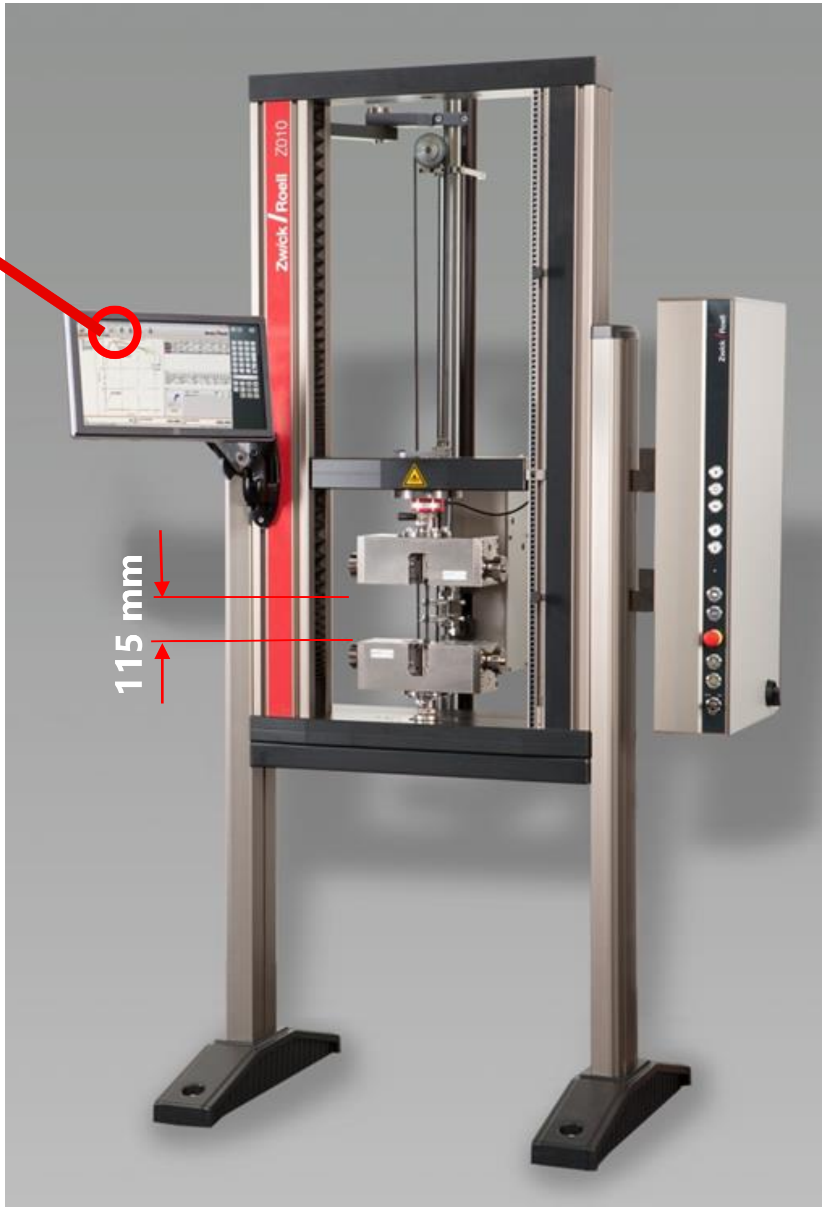
Preparation of the testing machine

Set the machine into a known configuration before starting the test !

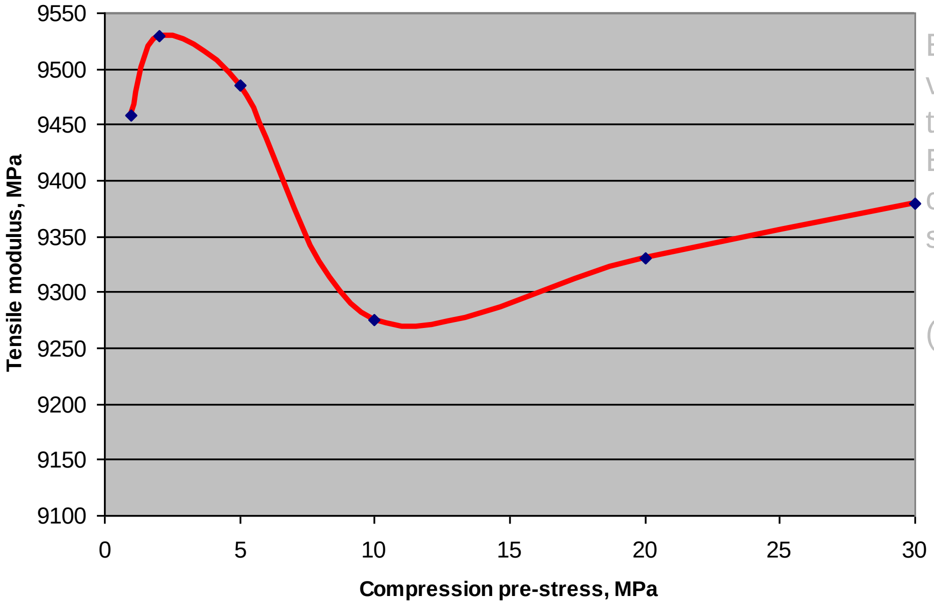




- Set the grip-to-grip separation to 115 mm
- Set the force measurement system to zero before the specimen is gripped at both ends

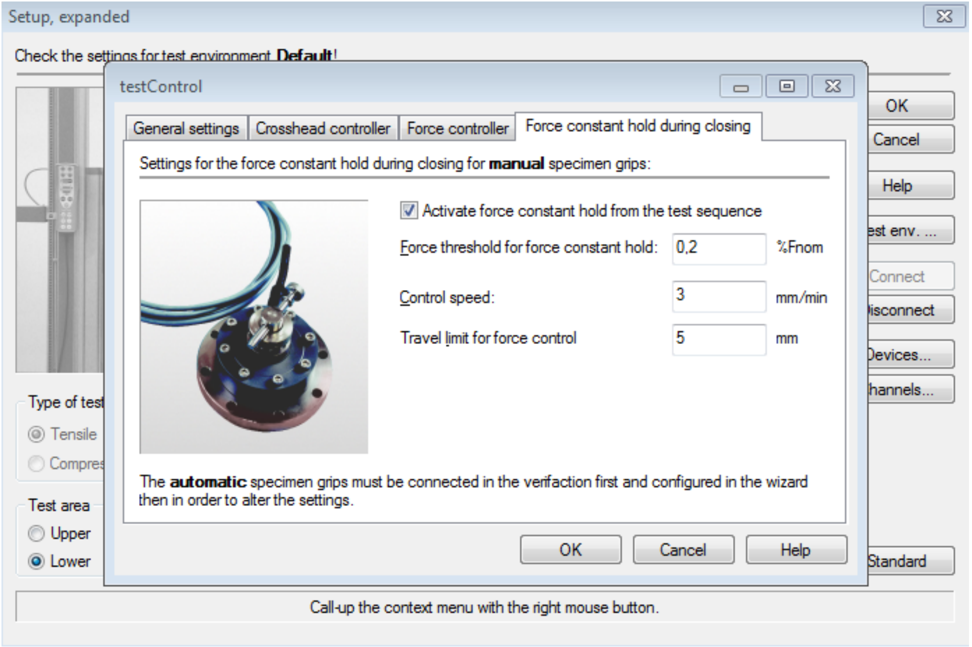
▶ Forces occurring during the clamping process in fact are really present on the specimen !

Pre-stresses that may occur during the clamping process shall be avoided, i.e. by using the force constant hold function of testXpert III.



Example of variation of tensile modulus, E_t , at different compression pre-stress levels.

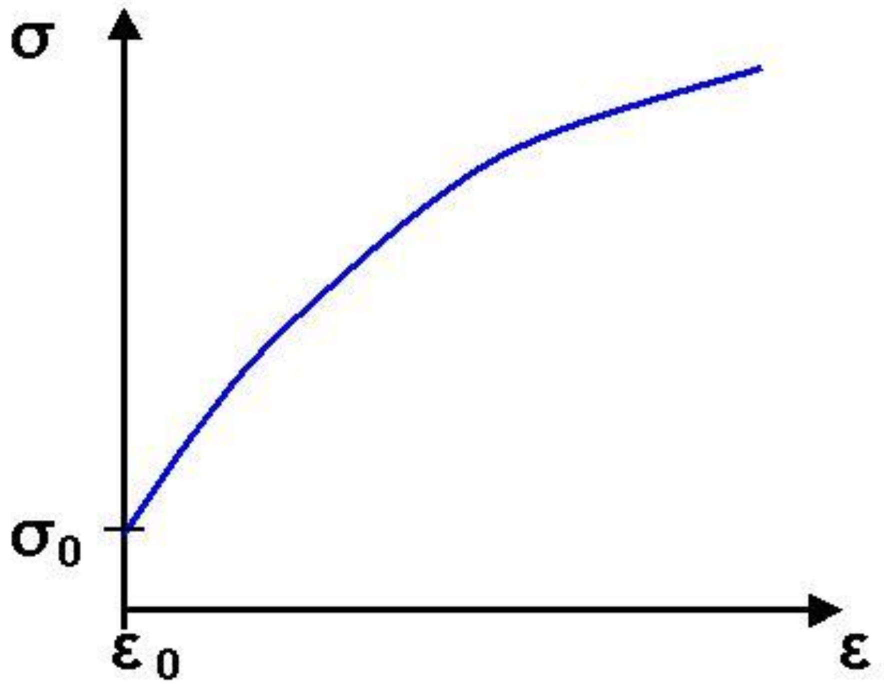
(PBT GF 10%)



Compression stresses during clamping may change the tensile modulus by more than 3 %

testXpert III settings to activate the function “Force constant hold during clamping”

A small preload helps to avoid a toe region



For modulus measurement:

$\sigma_0 \leq E_t / 2000$

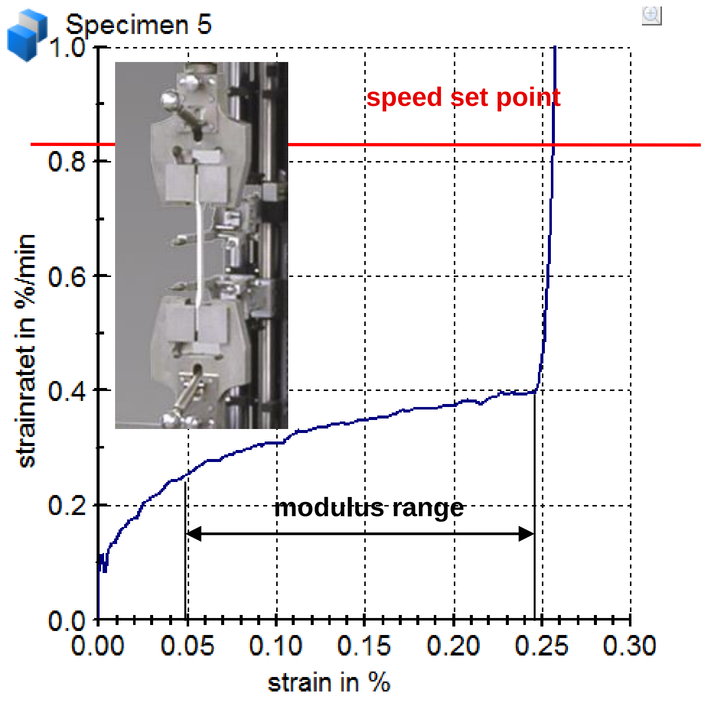
Means that the extension that is cut-off from the diagram is smaller than 0,05 %.

For measurement of relevant stresses:

$\sigma_0 \leq \sigma / 100$

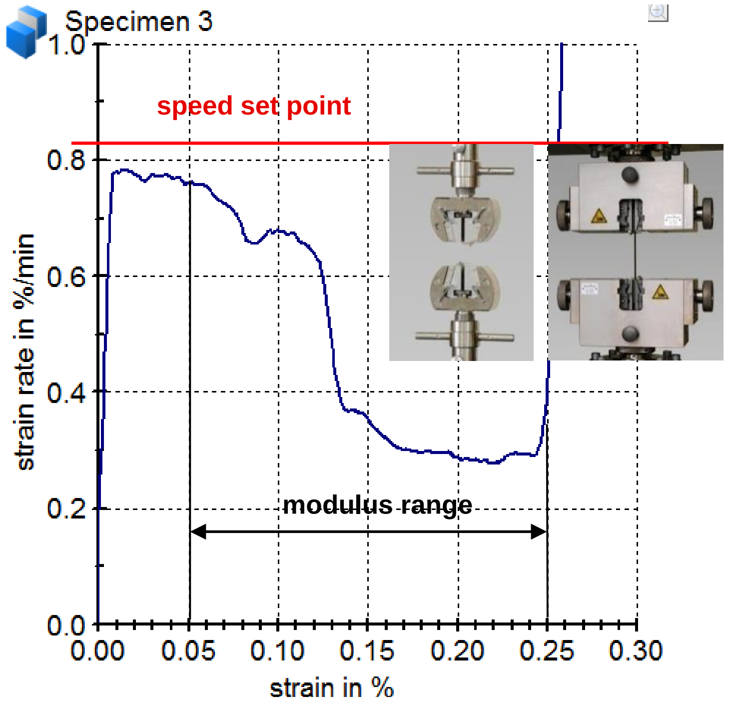
- The point of pre-stress σ_0 is the zero-point of extension
- This definition ensures a repeatable starting point of the test which is quite independent from operator or equipment influences.

Parallel clamping ensures the correct deformation speed being respected.



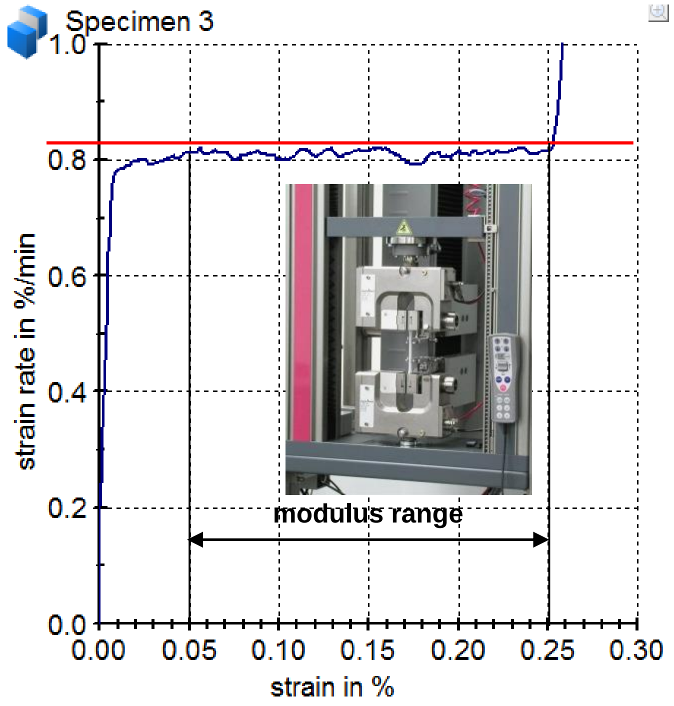
Self tightening wedge grips

Low, not constant, but repeatable strain rate profile



Pre-stressed self tightening grips

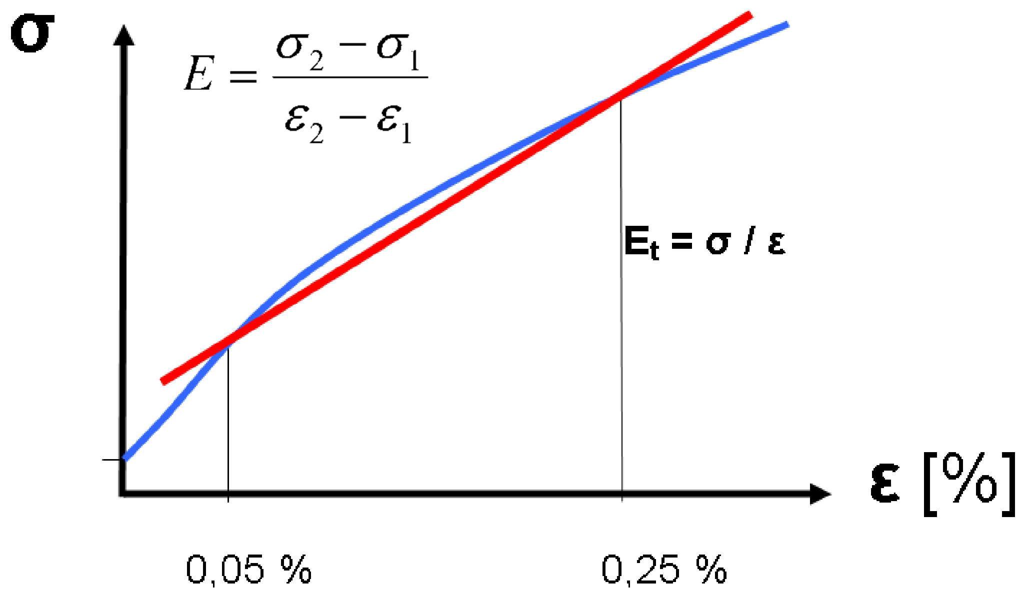
Strain rate starts well, but may change at increased force as wedges start moving



Parallel clamping pneumatic grips

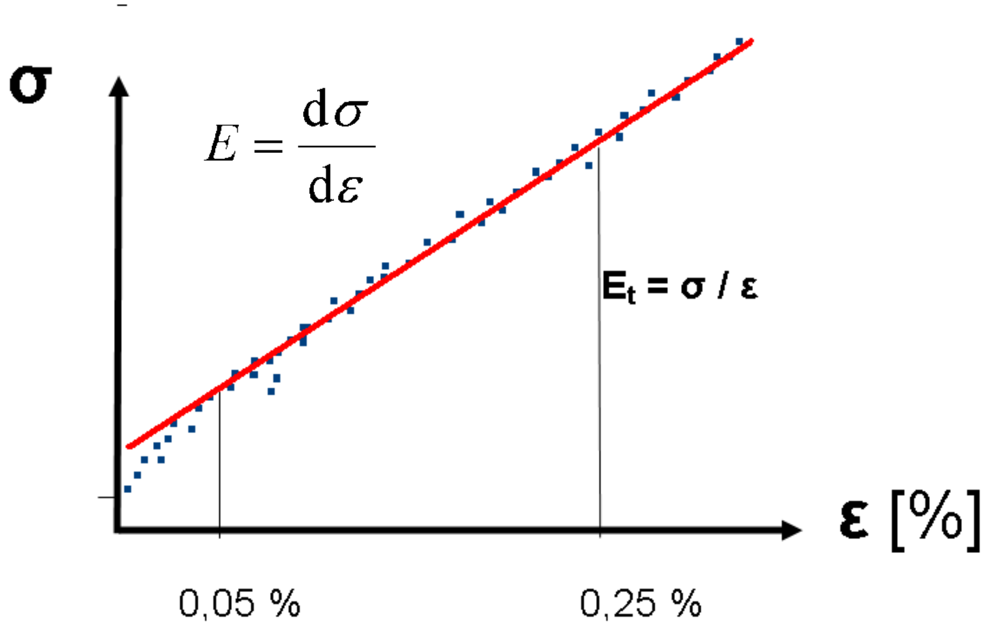
Constant strain rate throughout the test ensuring good reproducibility

The tensile modulus is calculated between 0.05% and 0.25% engineering strain and measured at low speed.



Secant slope

Easy to use for manual determination, statistically sensitive to noisy signals.

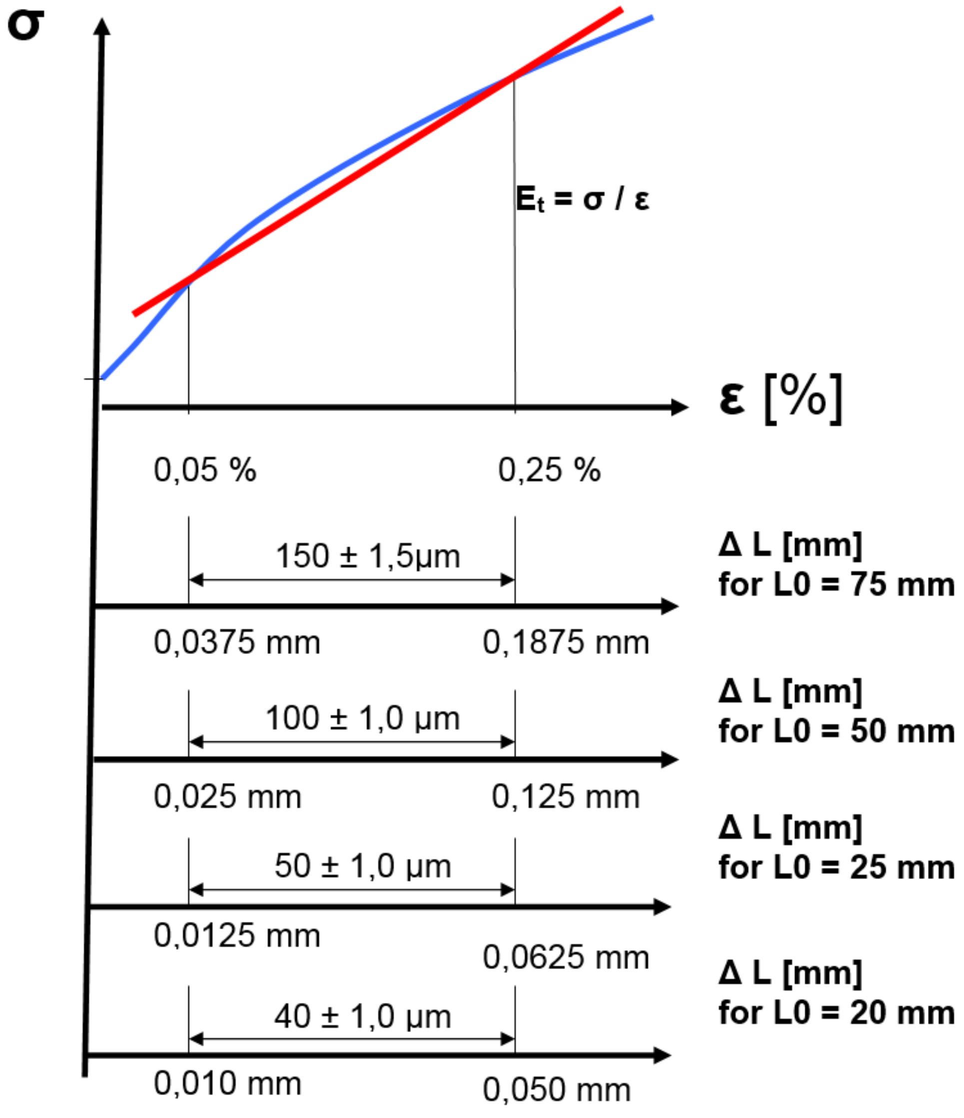


Regression slope

Takes into account all measured points and leads to statistically more safe results

Tensile modulus

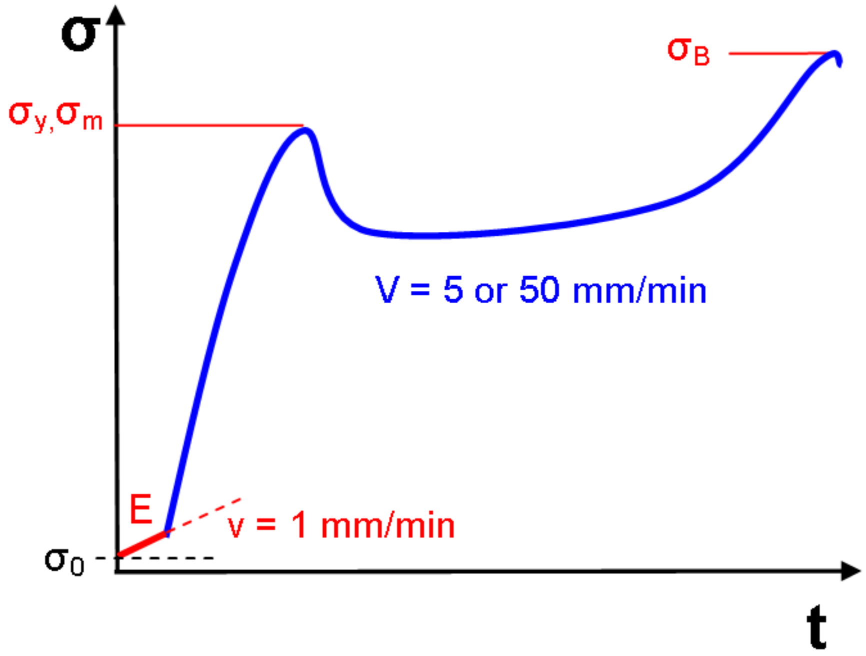
Modulus measurement requires for a highly accurate extensometer

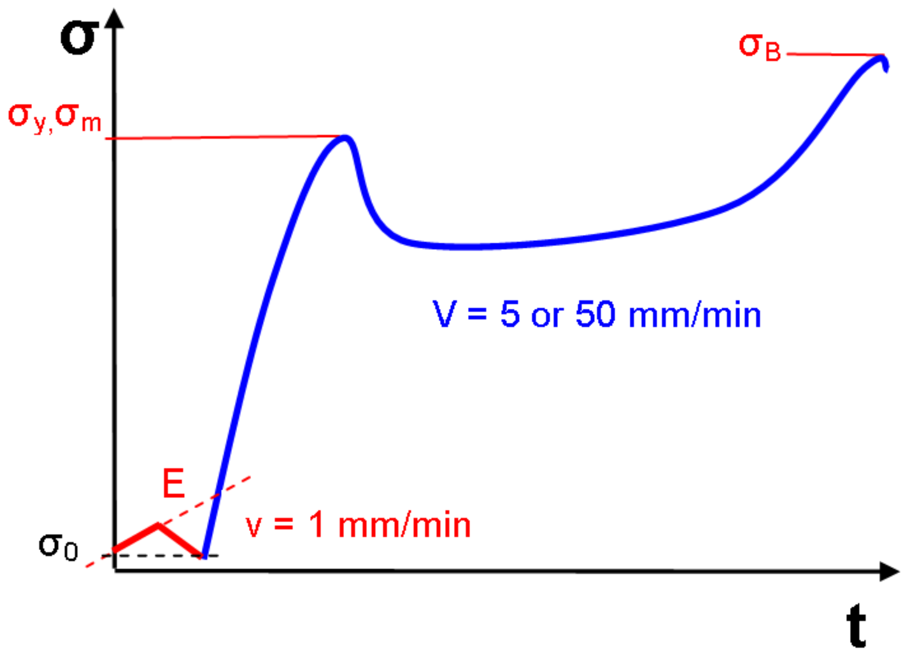


Extension measurement for modulus determinations

- Requirements to ISO 527-1, §5.1.5.1 :
  The modulus of elasticity is normally taken on the larger specimen types 1A or 1B. The accuracy requirement for the extensometer is ± 1,5 µm for type 1A and ± 1,0 µm for type 1B.
- The minimum requirement in terms of resolution, referencing to ISO 9513, lies therefore at 0.5 microns.
- For smaller specimens with smaller gage lengths the requirements remain at ± 1,0 µm.

After modulus determination the speed has to be changed. Typical speeds are 5 mm/min or 50 mm/min.

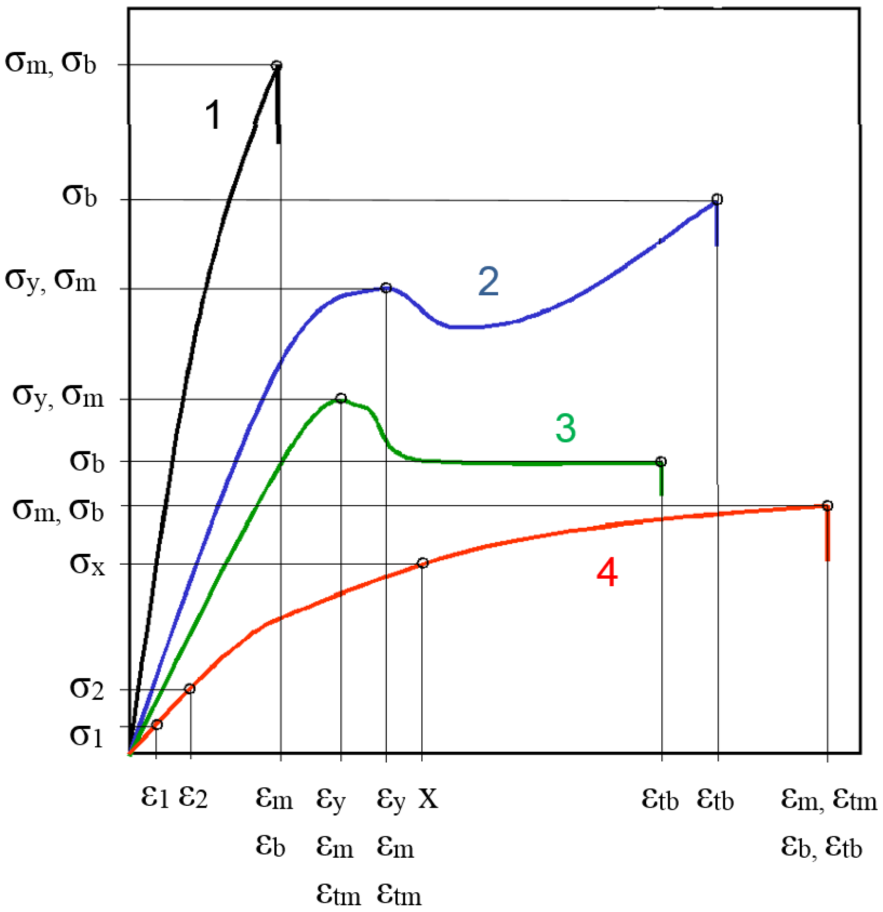


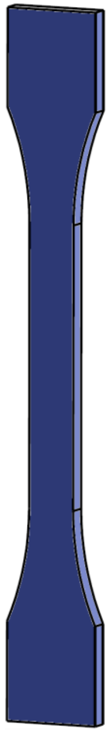


- Direct speed change after modulus determination is allowed
- Tensile modulus and further tests results may be determined from one single specimen

- It is preferable to unload the specimen before testing at a different speed, but it is also acceptable to change the speed without unloading.

ISO and ASTM distinguish four different types of stress-strain curves.





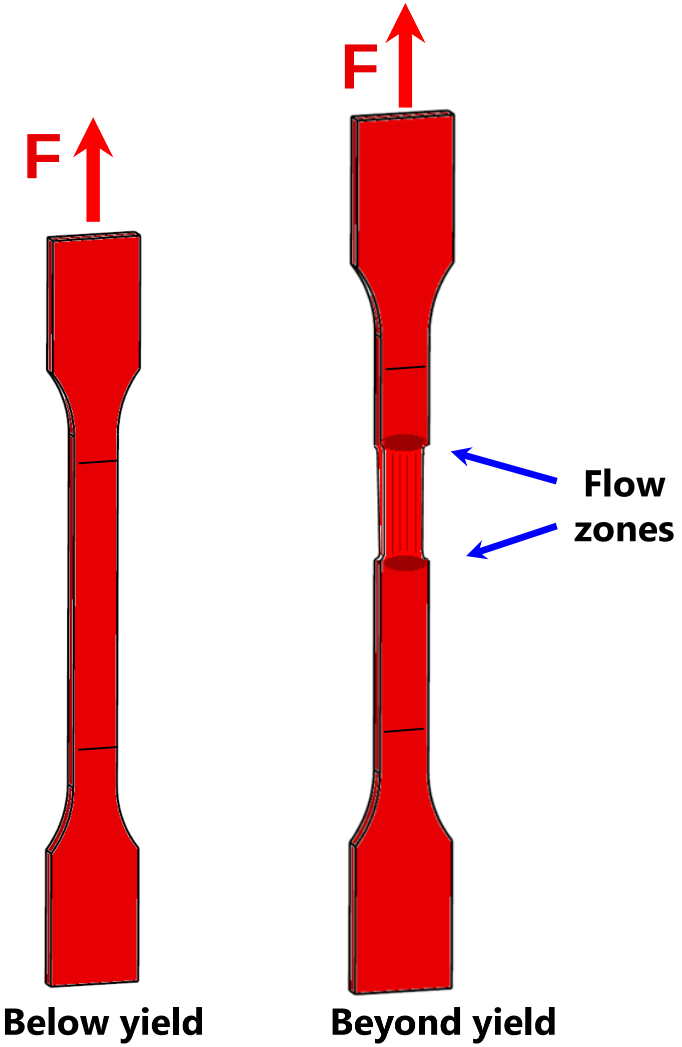
Stress-strain curve types:

- Curve 1: Brittle materials, low strain
- Curve 2 and 3: Tough materials with yield point
- Curve 4: Tough materials without yield point

Results:

- Tensile Modulus, E_t
- Yield point ε_y, σ_y,
- Maximum force point , σ_M, ε_M, ε_{tM} (Only first maximum !)
- Break point, σ_B, ε_B, ε_{tB}
- Strain results determined beyond a yield point are measured as "Nominal Strain"

Curve types 2 and 3 show a yield point.



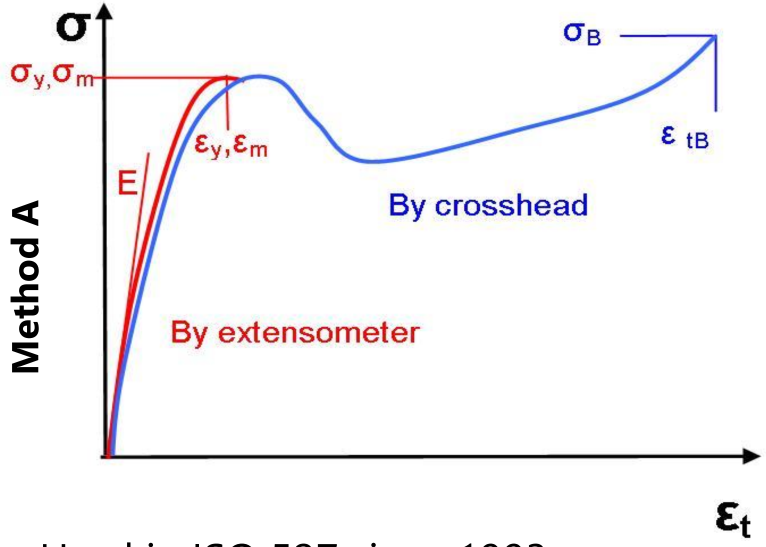
Inhomogeneous strain distribution beyond yield

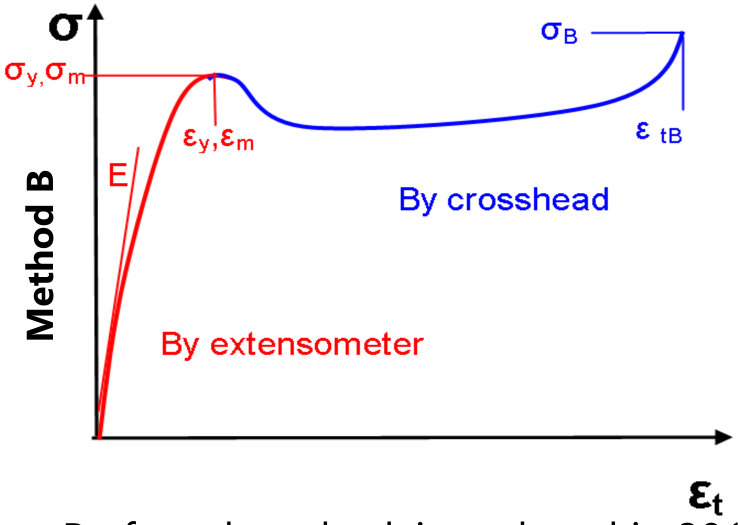
- Below yield, the strain is quite homogenously distributed within the parallel portion of the specimen.
- When approaching the yield point, the strain rate increases within a limited area while it decreases in other areas.
- Beyond yield very high strain rates can be observed within the flow zones. These local strain rates can be more than 10 times higher than the average strain rate.

Direct strain measurement beyond yield leads to statistically unsafe results

Nominal strain

Nominal strain is measured by the movement of the pulling clamp. There are two ways of measurement.





- Used in ISO 527 since 1993
- Needs <u>two</u> graphics to show all results correctly in stress-strain diagrams

➢ Strain: $\varepsilon = \Delta L_0 / L_0$

➢ Nominal Strain: $\varepsilon_t = \Delta L_T / L$

- Preferred method, introduced in 2012
- All results are shown in one single diagram
- There is only one definition for strain

➢ Strain at yield: $\varepsilon_y = \Delta L_y / L_0$

➢ Strain: $\varepsilon_t = \varepsilon_y + \Delta L_T / L$

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Agenda

1. History and scope
2. Test specimen
3. The tensile test
4. Comparable materials data
5. **Requirements to the test equipment**

   Force measurement
   Extension measurement

Calibration of force measurement to ISO 7500-1

Classification

Class of machine	Maximum permissible value, %					
	Relative error of				Relative resolution
	accuracy q	repeatability b	reversibility[1] $\lvert u \rvert$	zero f_0	a
0	± 0,5	0,5	0,75	± 0,05	0,25
1	± 1,0	1,0	1,5	± 0,1	0,5
2	± 2,0	2,0	3,0	± 0,2	1,0
3	± 3,0	3,0	4,5	± 0,3	1,5

1) The verification of reversibility shall only be carried out on request (see 5.4.8).

$$q = \frac{F_i - \bar{F}}{\bar{F}} \times 100$$

Relative accuracy error

$$b = \frac{F_{max} - F_{min}}{\bar{F}} \times 100$$

Relative repeatability error

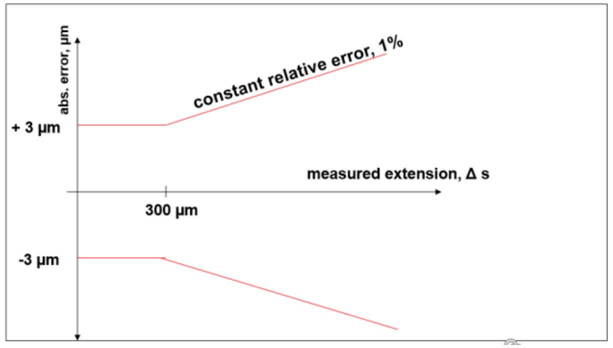
Extension measurement

Calibration of extension measurement to ISO 9513

Classification

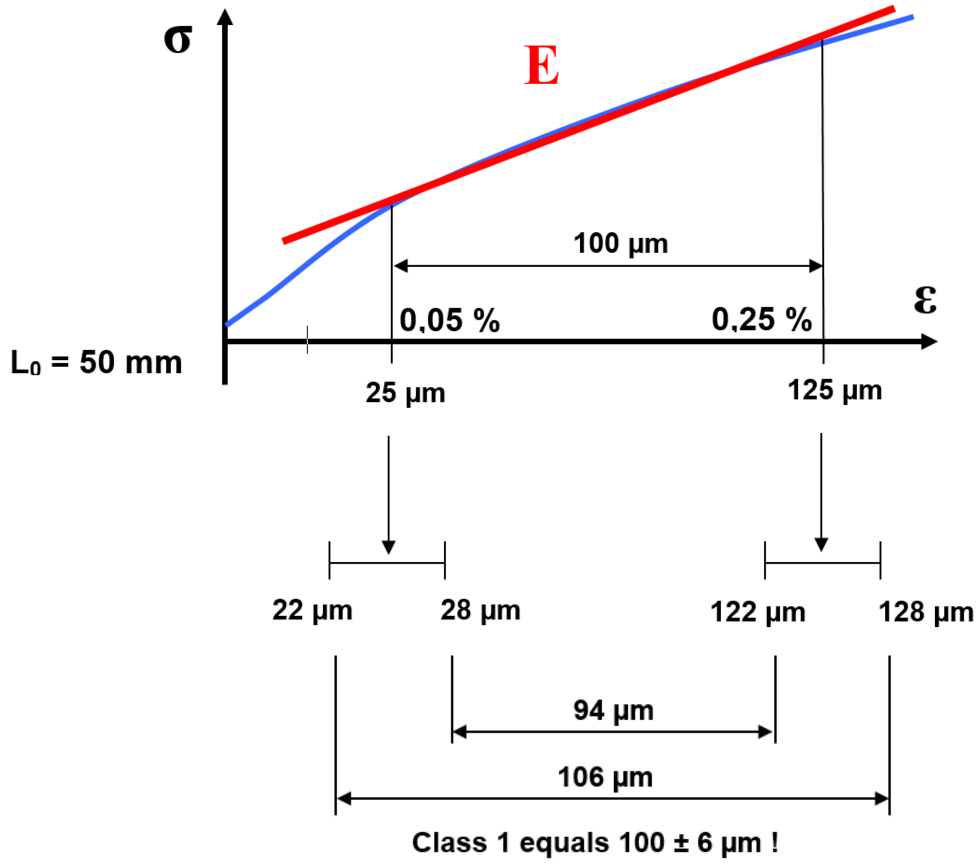
Class of extensometer	Extensometer (maximum values)				
	Relative error	Resolution (1)		Bias (1)	
	on the gauge length q_{Le} %	Percentage of readings r/l_i %	Absolute value r µm	Relative error q %	Absolute error $l_i - l_t$ µm
0,2	± 0,2	0,1	0,2	± 0,2	± 0,6
0,5	± 0,5	0,25	0,5	± 0,5	± 1,5
1	± 1,0	0,50	1,0	± 1,0	± 3,0
2	± 2,0	1,0	2,0	± 2,0	± 6,0

(1) Whichever value is the greater.



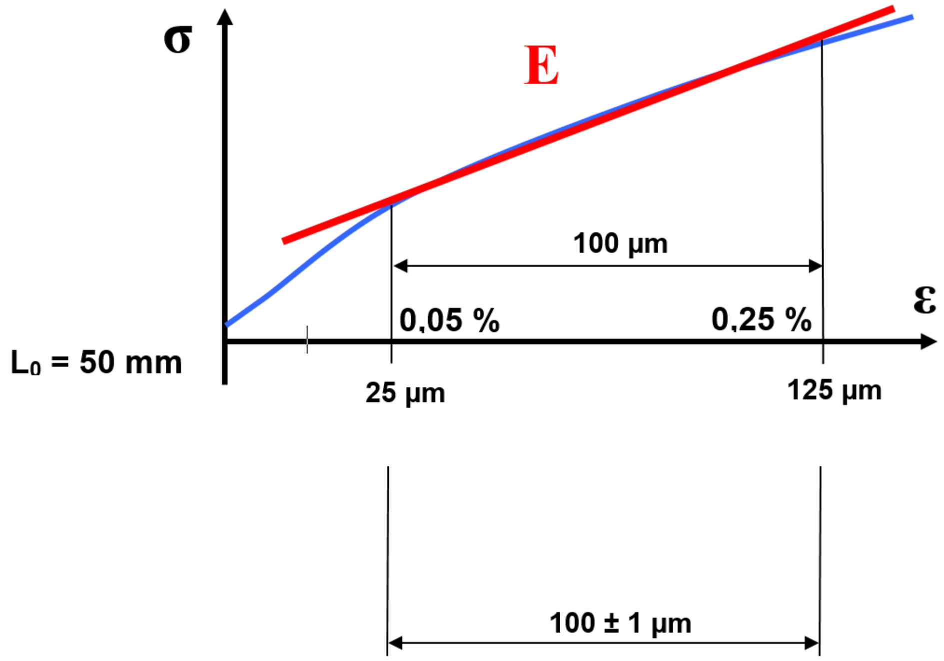
Example for class 1

A simple class 1 definition would allow an error contribution of ± 6% to the modulus.



- Tensile modulus is measured between 0.05% and 0.25% strain.
- This corresponds to an elongation of 25 and 125 microns for L_0 50 mm and a nominal distance of 100 microns between the measurement points.
- Class 1 of ISO 9513 allows a tolerance of ± 3 microns <u>on each measured point</u>.
- The real distance measured can therefore vary between 94 microns and 106 microns and thus lead to an error contribution of ± 6% (!) on the tensile modulus measurement.

A supplementary definition in ISO 527-1ensures reliable modulus measurements.



- Tensile modulus is measured between 0.05% and 0.25% strain.
- This corresponds to an elongation of 25 and 125 microns for L_0 50 mm and a nominal distance of 100 microns between the measurement points.
- Annex C of ISO 527-1 solves this problem by directly fixing a tolerance of only ± 1 micron to the distance between the measurement points.

These requirements for the extensometer accuracy go far beyond typical classifications!

Extension measurement

ISO 527-1 Annex C

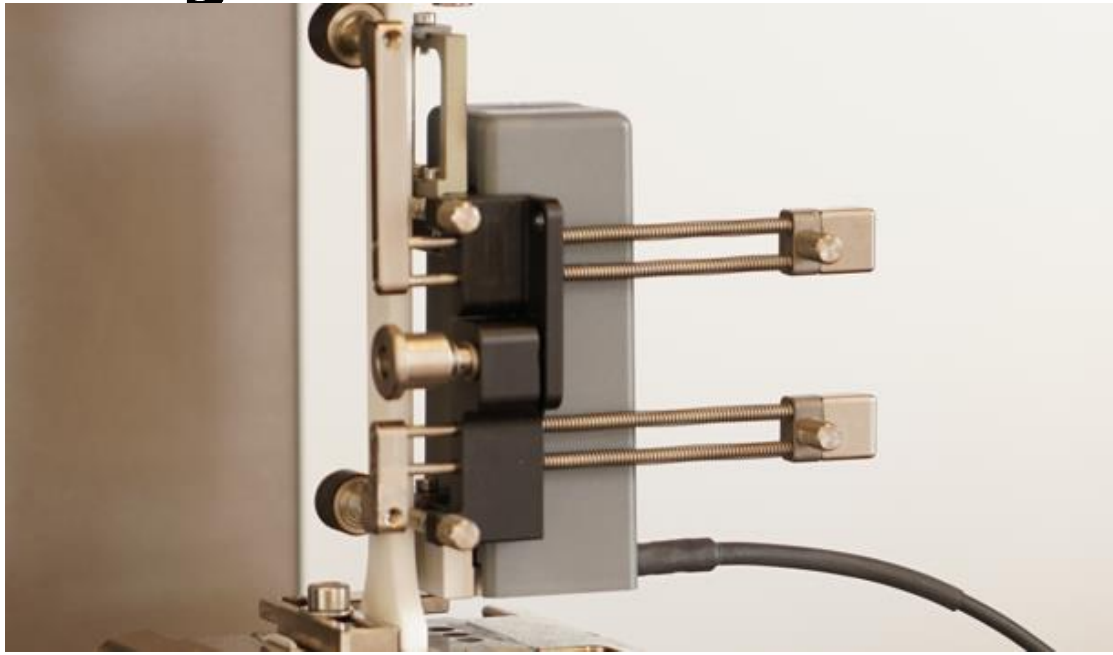
Prüfrichtung : Zug / Prüfraum: unten *Test direction: Tensile / Test area: lower*							
Messreihe 1 / *measurement row 1*			Messreihe 2 / *measurement row 2*			*U*	
l_i in mm	l_t in mm	q_b / q_{rb}	l_i in mm	l_t in mm	q_b / q_{rb}	in ± %	in ± µm
0,0196	0,0197	-0,1 µm	0,0196	0,0196	0,0 µm	2,54	0,5
0,0244	0,0246	-0,2 µm	0,0245	0,0245	0,0 µm	2,04	0,5
0,0396	0,0396	0,0 µm	0,0395	0,0395	0,0 µm	1,26	0,5
0,0796	0,0794	0,2 µm	0,0795	0,0792	0,3 µm	0,63	0,5
0,1194	0,1191	0,3 µm	0,1194	0,1191	0,3 µm	0,42	0,5
0,1247	0,1241	0,6 µm	0,1244	0,1241	0,3 µm	0,40	0,5
0,1597	0,1590	0,7 µm	0,1597	0,1590	0,7 µm	0,31	0,5
0,1999	0,1991	0,8 µm	0,1999	0,1990	0,9 µm	0,25	0,5

zusätzliche Prüfergebnisse nach ISO 527 / *additional test results according ISO 527* außerhalb akkreditiertem Leistungsumfang / *out of accredited scope*							
Stufe / *step*	Messreihe 1 *measurement row 1*		Messreihe 2 *measurement row 2*		Mittelwert beide Messreihen *avarage both rows*		*U*
l_i in µm	l_t in µm	q_b in µm	l_t in µm	q_b in µm	l_t in µm	q_b in µm	in ± µm
25,0 125,0	25,2 124,4	-0,2 0,6	25,0 124,7	0,0 0,3	25,09 124,55	-0,09 0,45	0,5 0,5

Messlänge *Gauge length* L_0 in mm	Veränderung der Längenänderung *Change in displacement* in µm	Differenz der Abweichungen *Difference of errors* in µm	Differenz der Abweichungen *Difference of errors* in %	Anforderung erfüllt *requirement fulfilled*
50	100	0,54	0,54	ja / yes

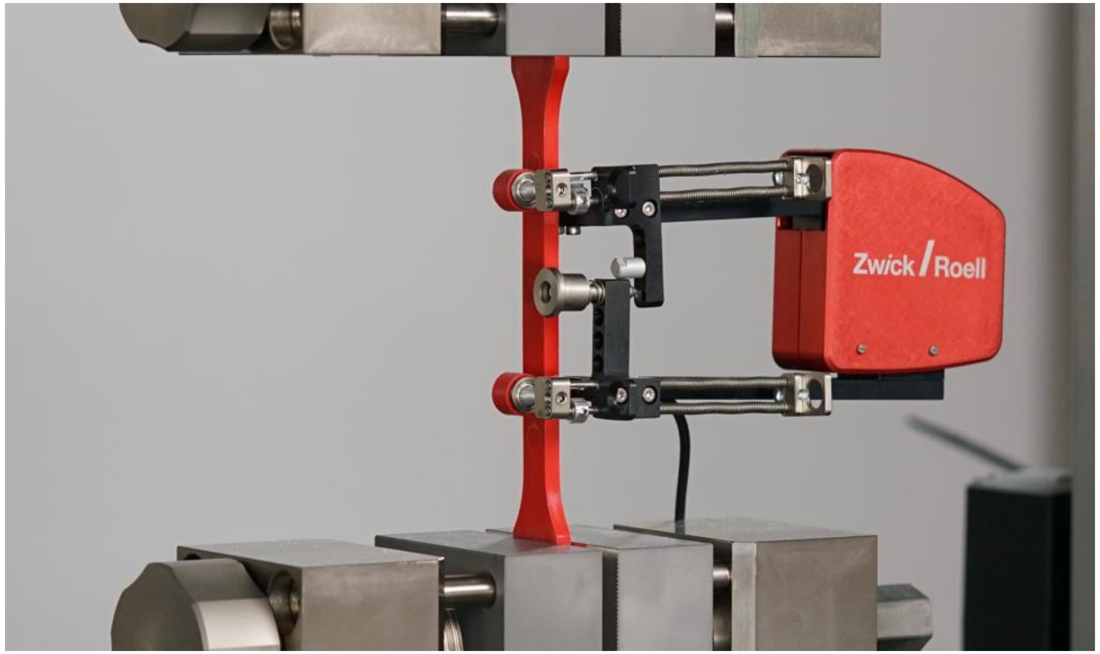
The proof to this definition can easily be shown by any calibration protocol, if the typical extensions for modulus measurement have been verified.

Manual clip-on extensometers provide accurate modulus measurement and enough travel to measure yield point elongation.



Digiclip – digital clip-on extensometer

• Range:	13.5 mm or 40mm
• Accuracy:	class 0.5 (ISO 9513)
• Gage length:	20 to 105 mm
• Type of measurement:	digital - optical



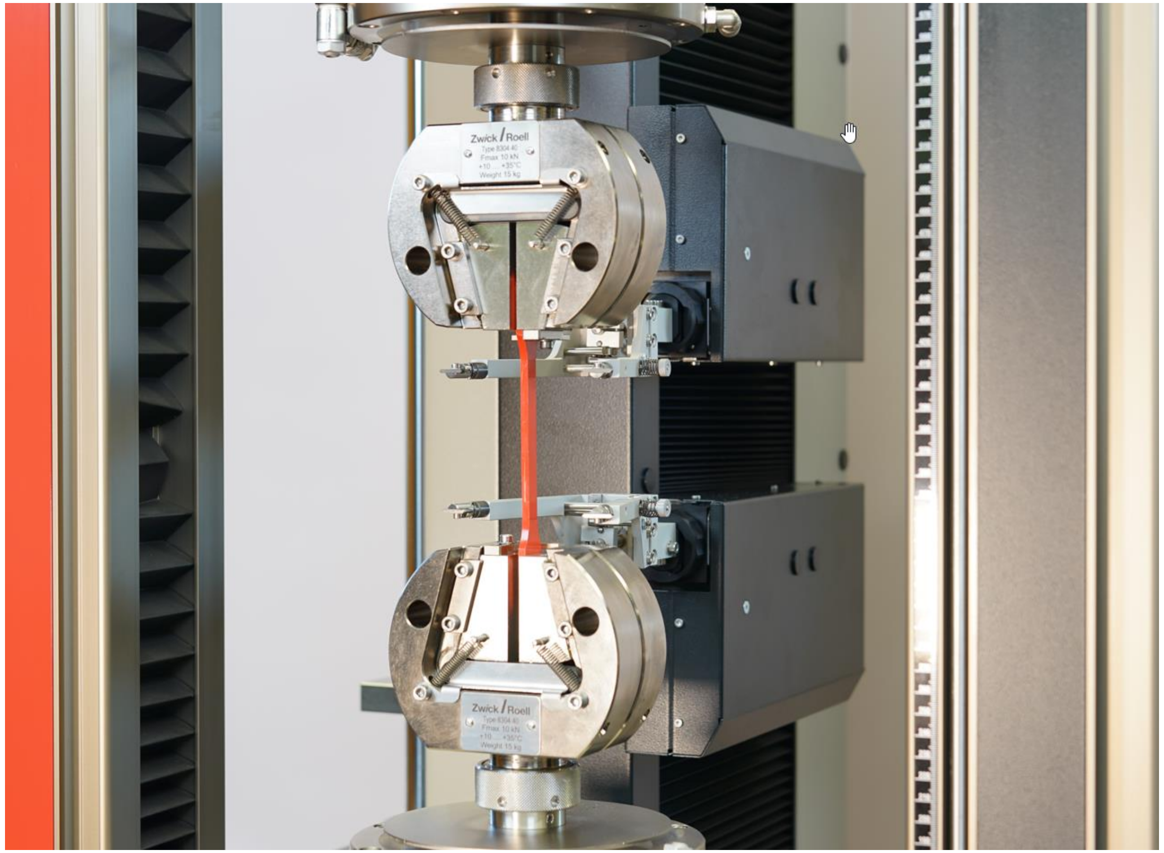
Clip-on extensometer 5025-1, 7537-1

• Range:	25 mm or 37.5 mm
• Accuracy:	class 0.5 (ISO 9513)
• Gage length:	50 or 75 mm
• Type of measurement:	strain gages

The automatic digital extensometer makroXtens provides accurate modulus measurement combined with sufficient travel to measure the yield point elongation.

- **Technical data:**
- Range: 75 mm to 160 mm
- Resolution: 0.12 µm to 0.6 µm
- Accuracy: class 1 to ISO 9513
- Gage length: 10 to 205 mm
- Measuring system: incremental - optical
- Motorized feeler arms
- Rotatable knife edges for break measurement
- Crash sensor for secure operation
- Optional: motorized gage length set

The automatic digital multiXtens extensometer provides accurate modulus measurement combined with ability to measure high elongation up to specimen break.

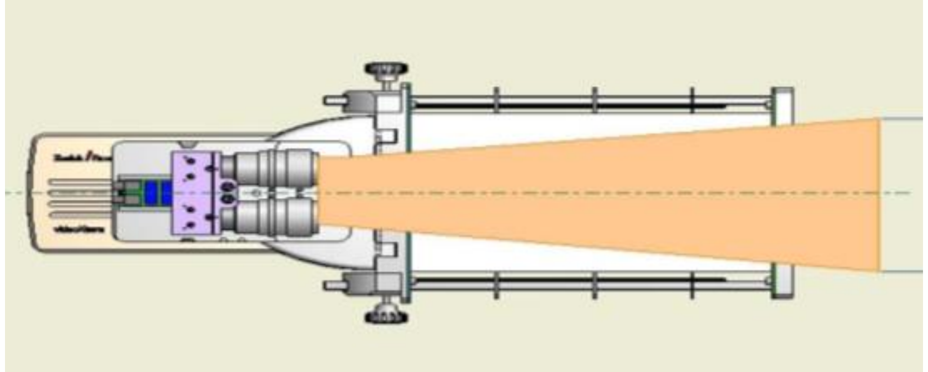


- **Technical data:**
- Range: 740 mm minus gage length
- Resolution: 0.2 µm to 0.4 µm
- Accuracy: class 0.5 to ISO 9513
- Gage length: 10 to 500 mm
- Measuring system: digital
- Motorized feeler arms
- Rotatable knife edges for break measurement
- Crash sensor for secure operation
- Motorized gage length set
- Automatic centering function
- Accurate testing acc. to ASTM and ISO standards

The optical extensometer videoXtens HP achieves accuracy grade 0.5 and can be used for tensile modulus measurements.

- Key features are
  - Double camera system
  - Adaptable tunneling
  - Integrated LED lightning
  - Resolution down to 0.25 microns
  - Large field of view (128 or 145 mm)

- Benefits
  - Reliable measurements for many materials, including plastics
  - Insensitive to environmental conditions
  - Fulfils ISO 527 modulus requirements.



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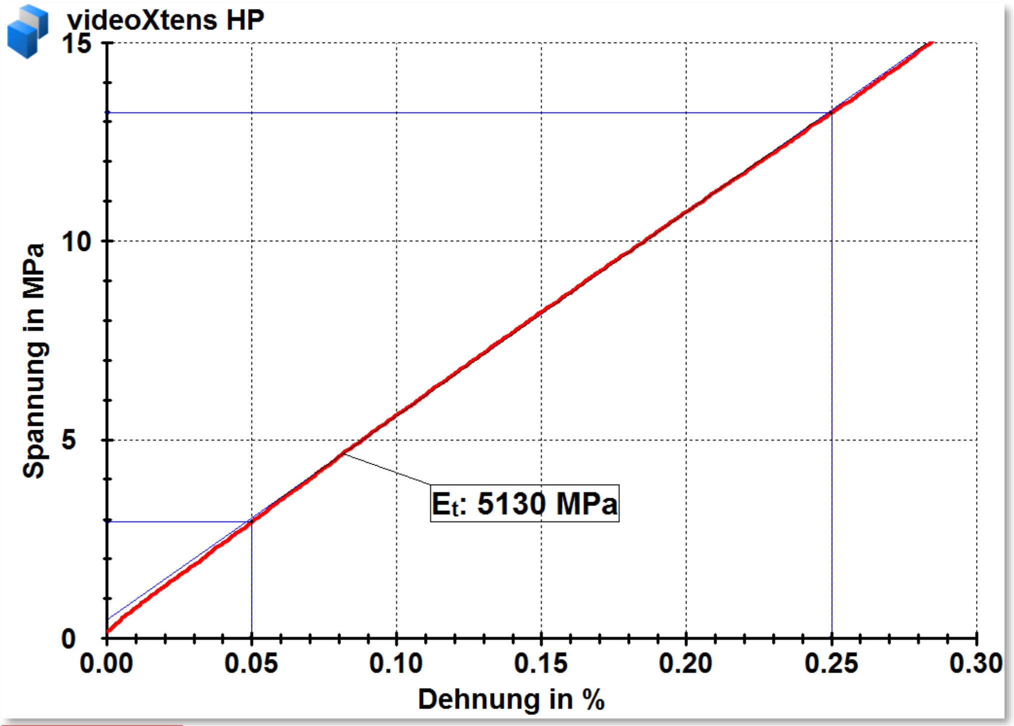
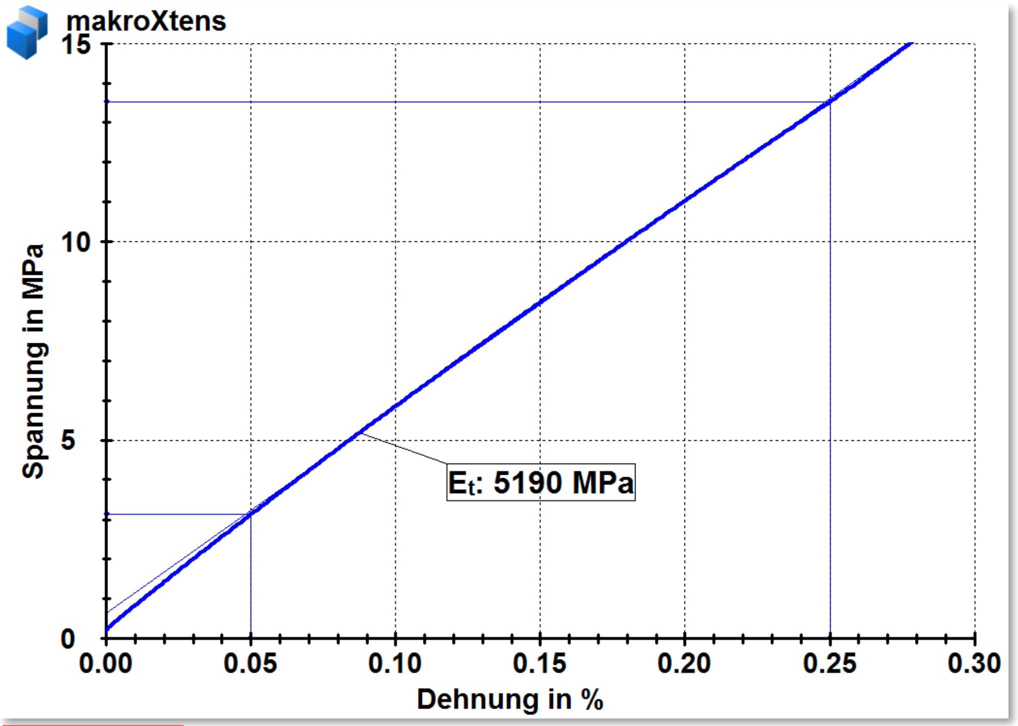
The measurement quality of a videoXtens HP is comparable to that of the mechanic makroXtens.



Measurement curve, optical videoXtens HP



Measurement curve, mechanical makroXtens

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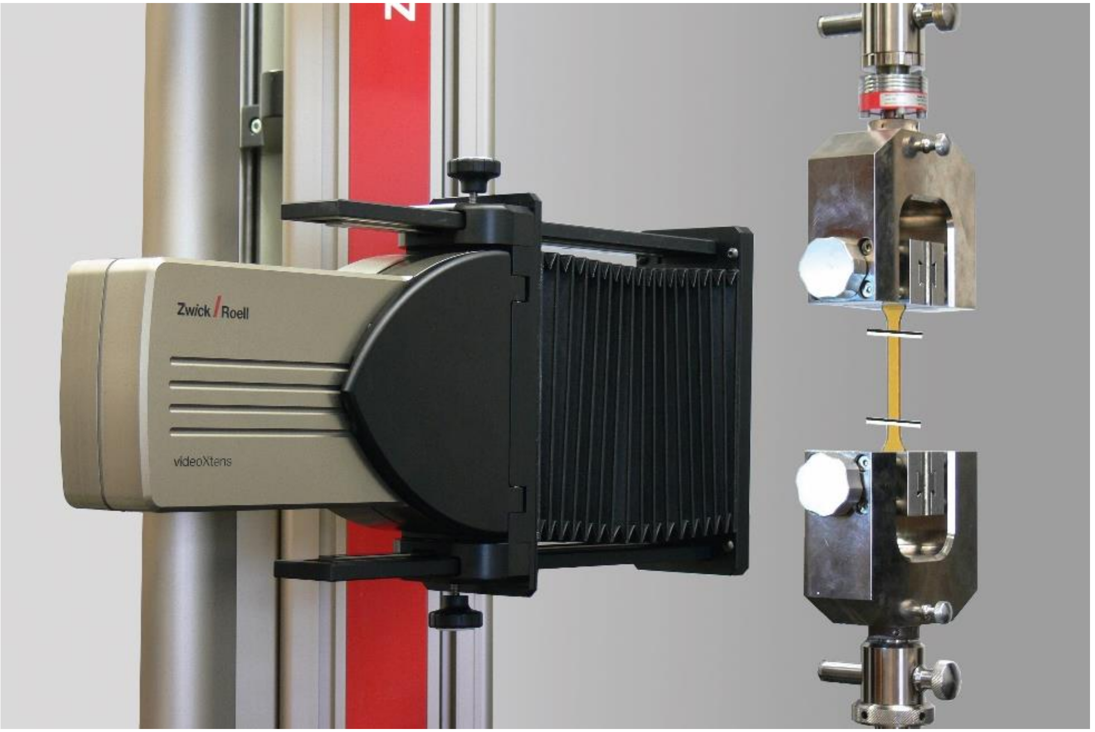
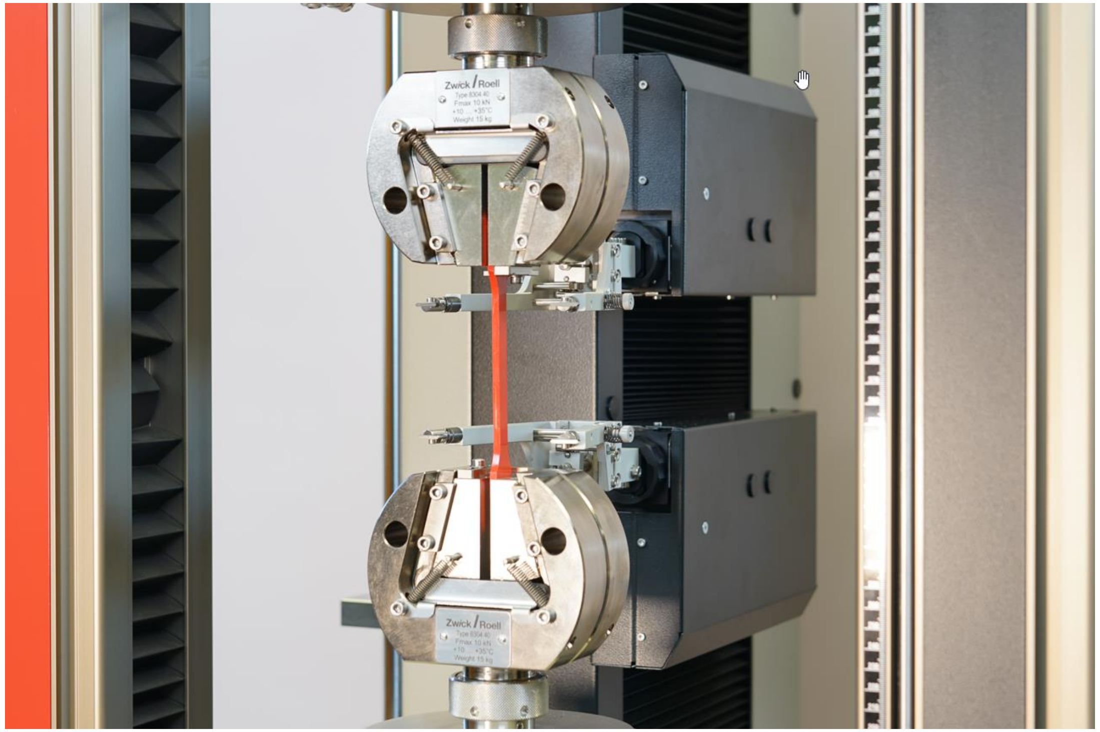
Several types of optical and mechanical Zwick extensometers fulfill demanding requirements



videoXtens HP



multiXtens, makroXtens

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accurate *repeatable* *reproducible* *traceable*

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