An introduction to composites testing

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Zwick Roell

Agenda

1. Introduction
2. Tensile, compression, shear, flexure and ILSS testing
3. Static testing machines
4. Strain and displacement measuring systems

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Applications of composite materials

With excellent weight-specific mechanical properties and fatigue response and a design flexibility, due to a variety of fibers, matrix systems and fiber architectures, composites are used in many application areas.

Other application areas:

- Construction
- Sports & Leisure
- Electronics
- Oil & Gas

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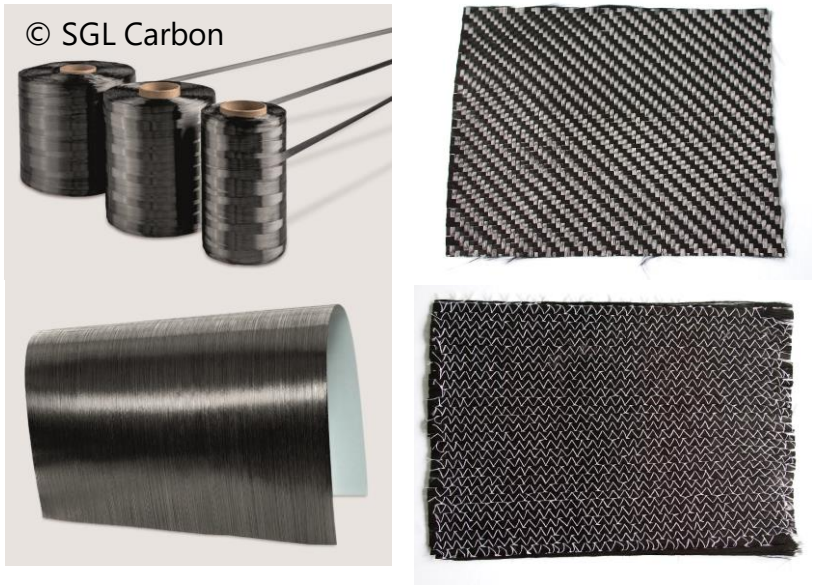
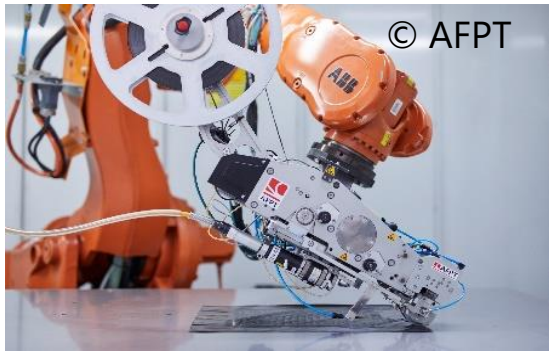
In addition to the fiber type, matrix system and textile architecture, the mechanical material response is greatly influenced by the composite manufacturing process.

Materials



- Different fiber types
- Different resin systems
- Different textile architectures

Processes



- Autoclave curing of thermoset prepreg composites
- Resin Transfer Molding (RTM) at low or high pressure
- Vacuum Assisted Resin Infusion (VARI)
- Automated Fiber Placement (AFP)
- Automated Tape Laying (ATL)
- Filament winding
- Pultrusion
- Wet pressing
- Press forming of thermoplastic composites
- …

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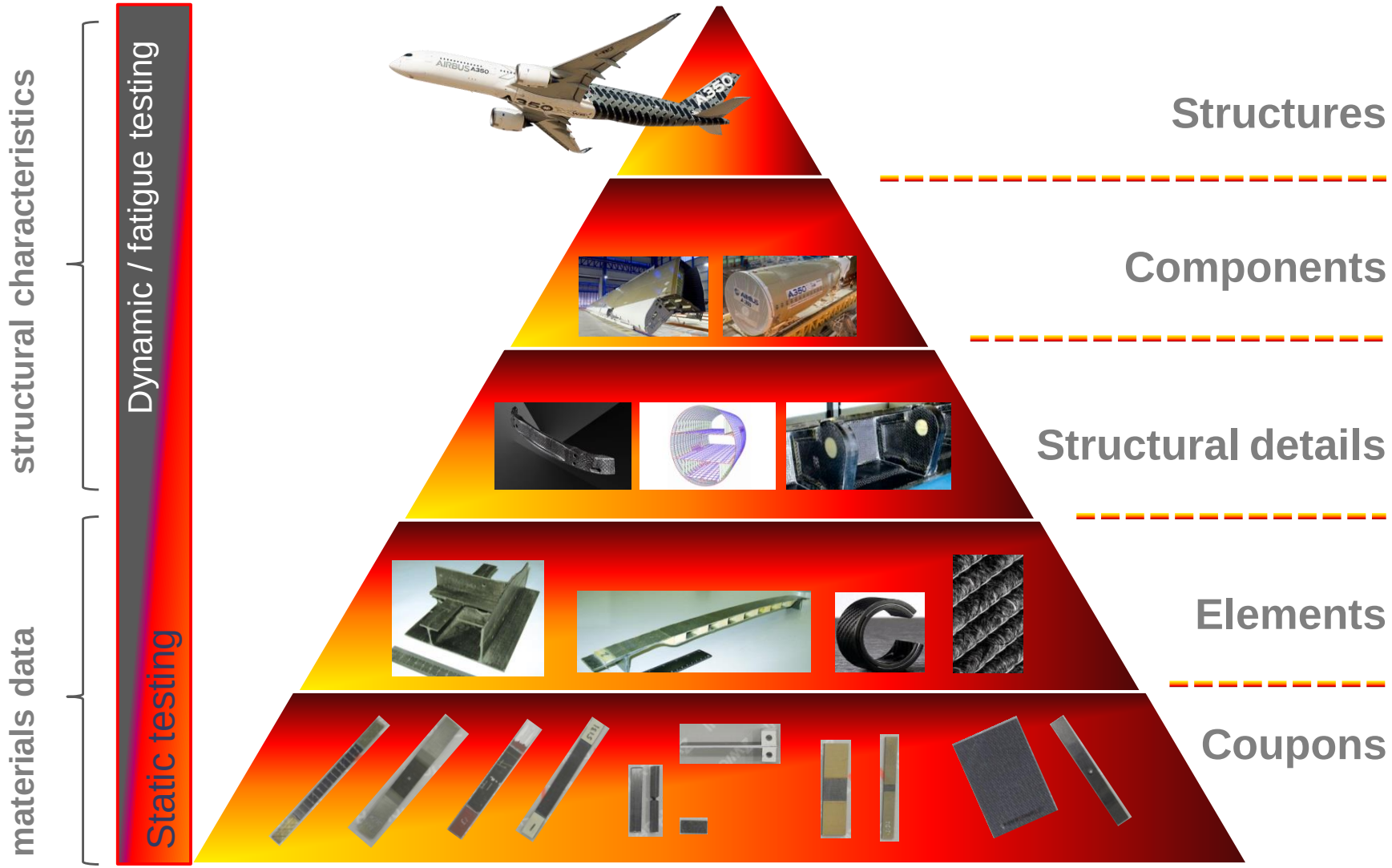
Testing pyramid or building block approach



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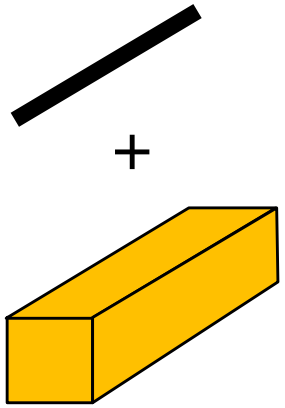
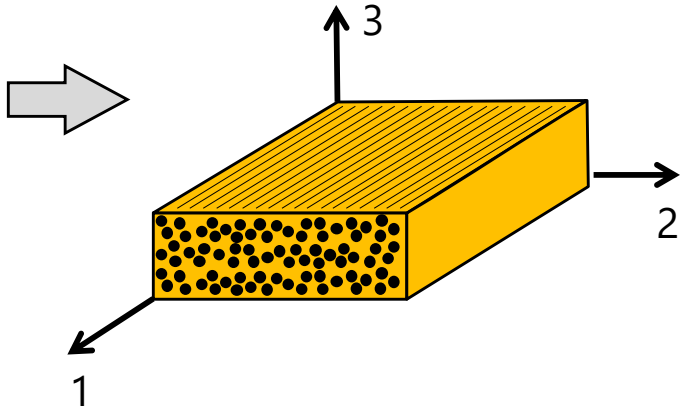
Composites are orthotropic materials, where normal and shear properties are independent.

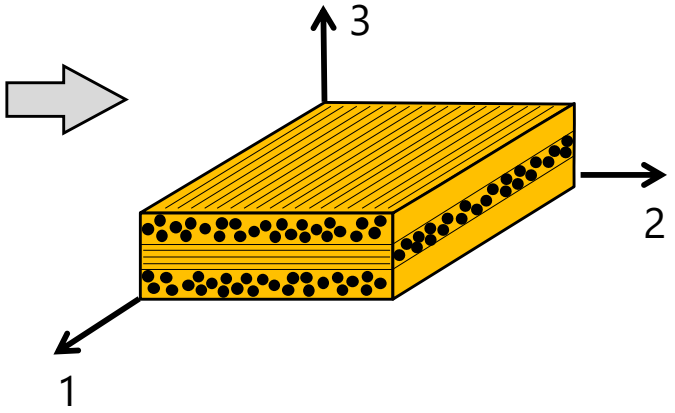
fiber + matrix



unidirectional ply



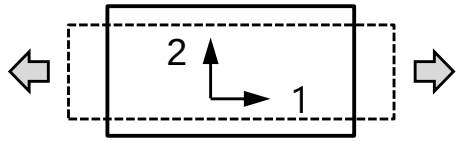
multidirectional laminate



Basic static in-plane material properties

elastic	E_1 , E_2 , G_{12} , ν_{12}
strength	F_1^{tu} , F_2^{tu} , F_1^{cu} , F_2^{cu} , F_{12}

Poisson ratio



$$\nu_{12} = -\frac{\Delta\varepsilon_2}{\Delta\varepsilon_1}$$

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The material properties of UD composites in fiber and matrix direction vary significantly.

UD carbon-epoxy prepreg material system used for Aerospace composite structures

Basic elastic properties (in-plane)						Basic strengths (in-plane)					
		SI		Imperial				SI		Imperial	
longitudinal tensile modulus	E_1^t	165	GPa	23.9	msi	longitudinal tension	F_1^{tu}	2700	MPa	391.6	ksi
transverse tensile modulus	E_2^t	12	GPa	1.7	msi	Transverse tension	F_2^{tu}	60	MPa	8.7	ksi
Longitudinal compressive modulus	E_1^c	165	GPa	23.9	msi	Longitudinal compression	F_1^{cu}	1500	MPa	217.6	ksi
Transverse compressive modulus	E_2^c	12	GPa	1.7	msi	Transverse compression	F_2^{cu}	250	MPa	36.3	ksi
In-plane shear modulus	G_{12}	5.5	GPa	0.8	msi	In-plane shear	F_{12}	100	MPa	14.5	ksi
Poisson's ratio	ν_{12}	0.3	-	0.3	-						

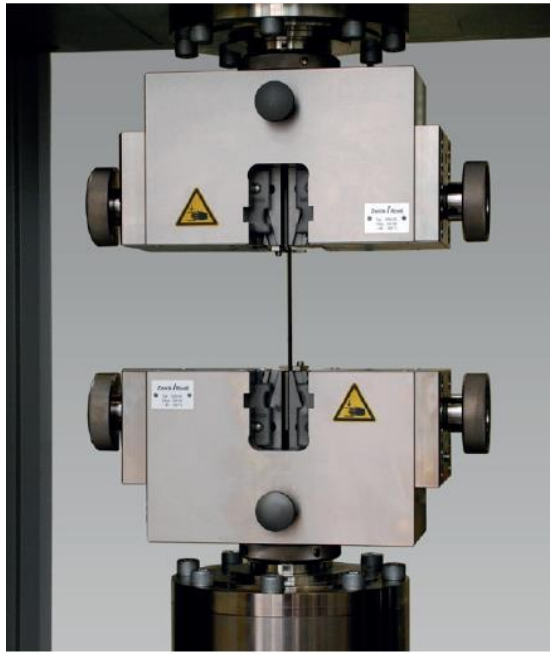
Tension

Compression

Shear

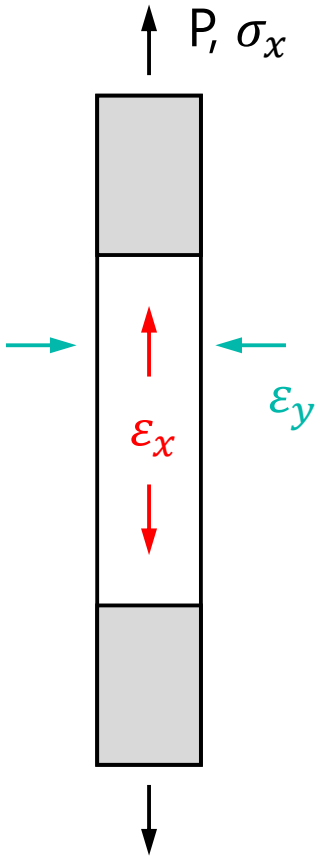
ZwickRoell offers different grips for tension testing of composites that satisfy different customer needs.

mechanical body-over-wedge grip



wedge screw grip

hydraulic body-over-wedge grip



Some international standards to determine the tensile mechanical properties of advanced composite materials

ISO 527-4	*EN 2561*	*DIN 65378*	*ASTM D 3039*	*Airbus AITM 1.0007*
ISO 527-5	*EN 2597*	*DIN 65469*	*prEN 6035*	*Boeing BSS 7320*

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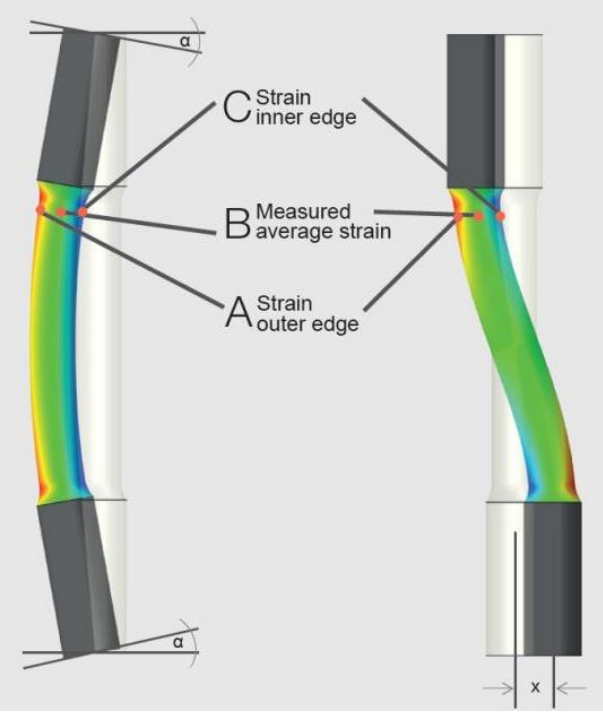
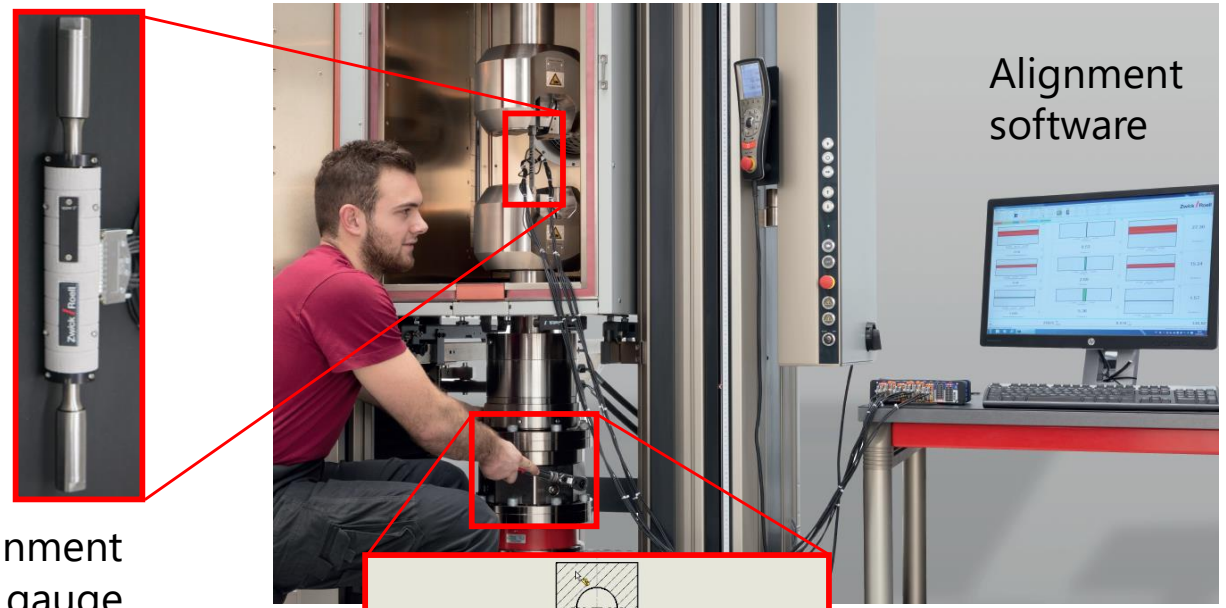
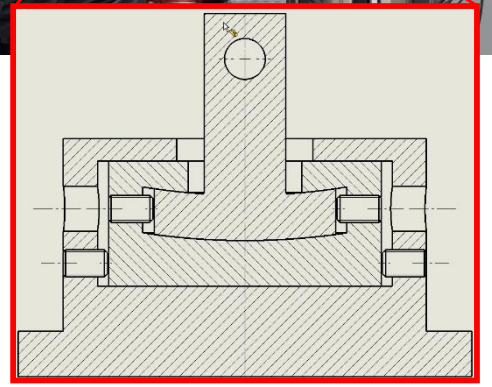
Misalignment has a strong effect on tests with brittle materials. We offer a complete portfolio for alignment of the load axis.



ISO 23788	ASTM E 1012	Nadcap Audit criteria 7122



Alignment gauge



Alignment unit

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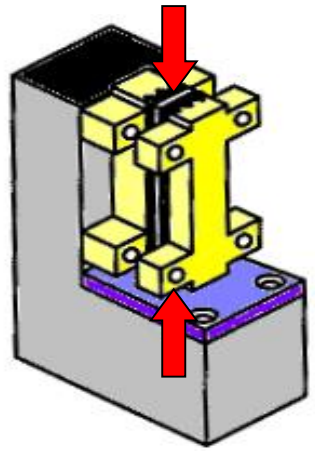
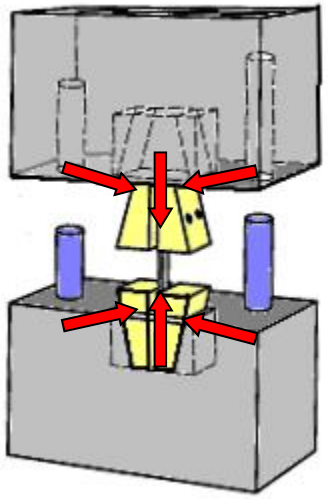
Different methods exist, distinguished by the type of loading.

End Loading



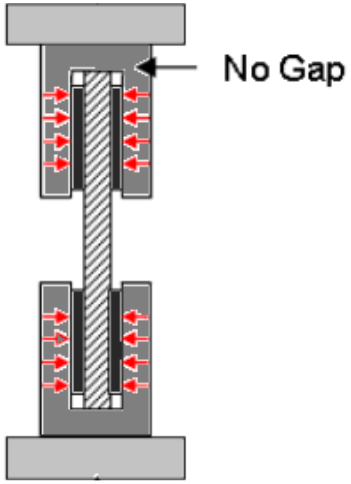
ISO 14126 method 2
ASTM D 695
Boeing BSS 7260 type III & IV
DIN EN 2850 type B

Shear Loading



ISO 14126 method 1
ASTM D 3410
Airbus AITM 1.0008
DIN EN 2850 type A

Combined Loading



ISO 14126 method 2
ASTM D 6641
Airbus AITM 1.0008

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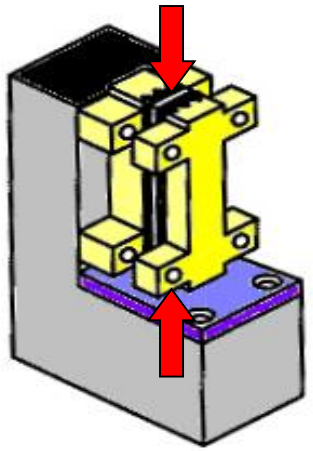
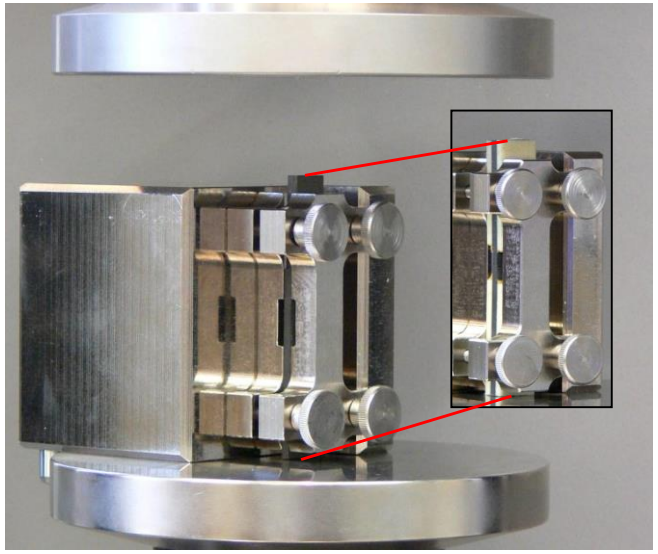
End loading compression tools are variants of the ASTM D 695 tool, initially developed for plastics testing.

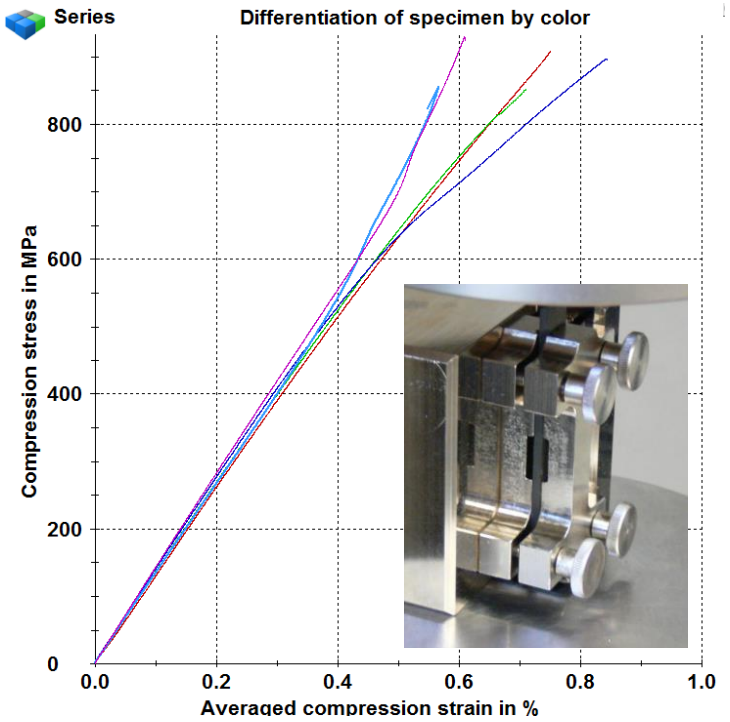
End Loading





- ZwickRoell's end loading compression tool includes guides for both, Modulus (center) and Ultimate Strength (right) measurement.
- It is always well centered to the loading axis of the machine.

Untabbed specimens, used for modulus measurement, break early at the specimens end.



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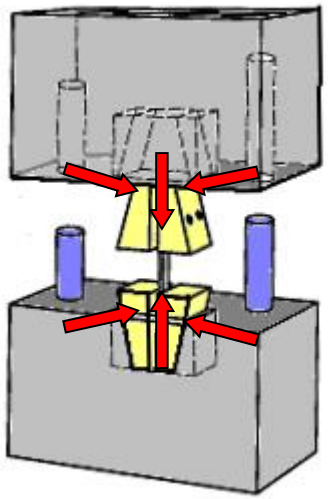
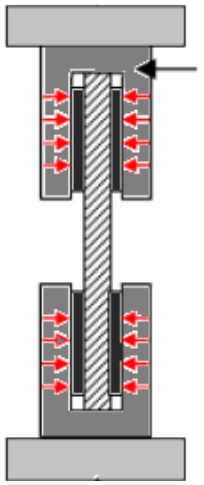
The HCCF covers shear loading and combined loading standards, is easy to operate and supplies reliable test results.

Shear Loading

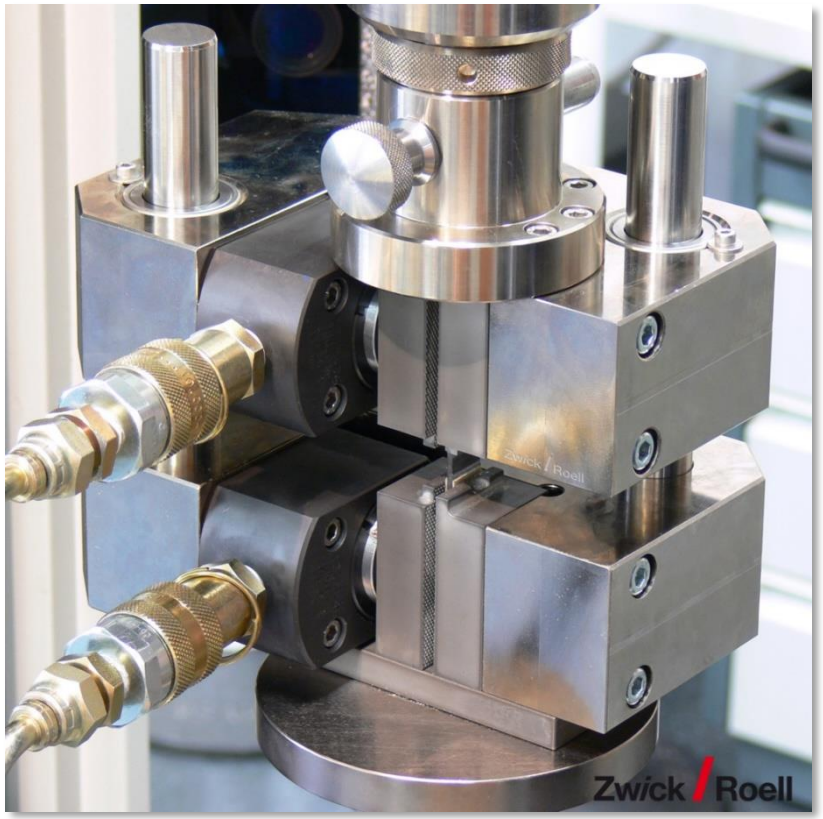


Combined Loading



Features of the HCCF

- Hydraulic parallel clamping principle
- Shear loading up to about 40 kN
- Combined loading up to 200 kN
- Up to 35 mm wide specimen possible
- No movements of jaw faces during test
- Exact alignment of the jaw faces
- Initial misalignments due to tab or glue thickness differences are visible at the moment of clamping and can be corrected
- The HCCF must not be removed from the test machine, which increases specimen trough-put
- Adjustable specimen end-stops
- Free access, simple cleaning



HCCF – Hydraulic Composites Compression Fixture

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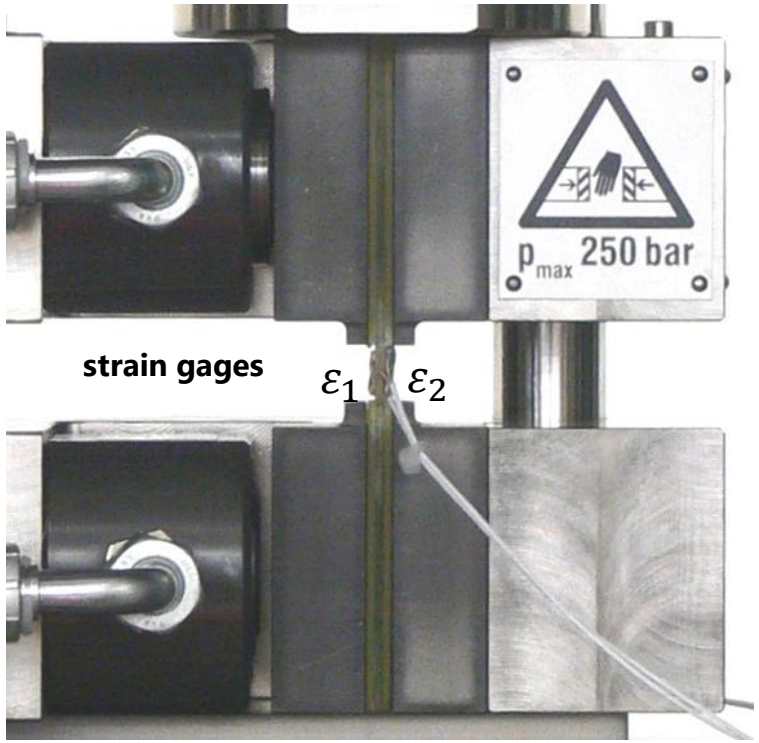
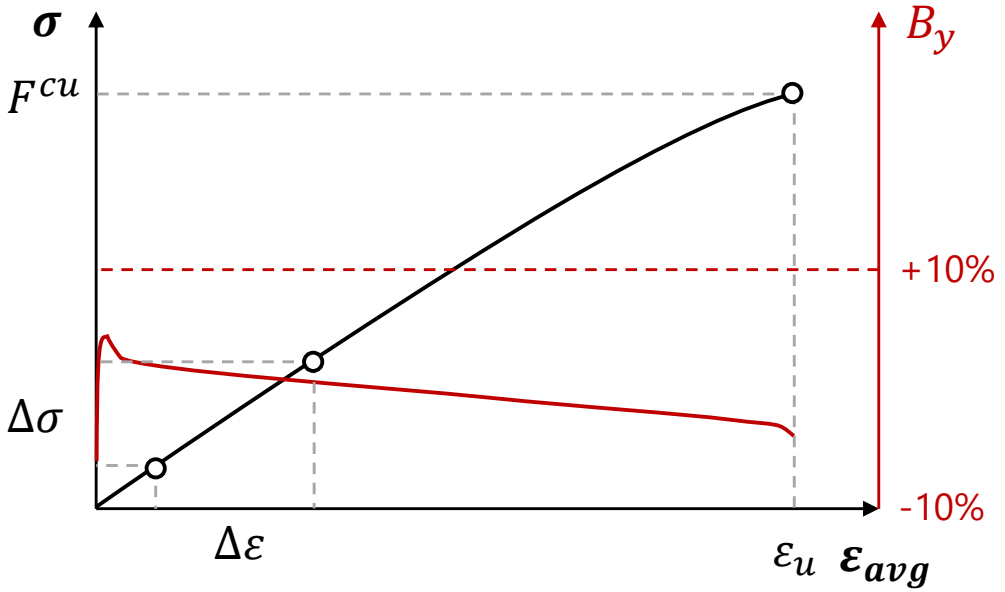
Two opposing linear strain gauges are needed to verify the validity of the test.





$$E_c^{chord} = \frac{\Delta\sigma}{\Delta\varepsilon}$$

$$F^{cu} = \frac{P^{max}}{A}$$

$$B_y = \frac{\varepsilon_1 - \varepsilon_2}{\varepsilon_1 + \varepsilon_2} \times 100$$

E_c^{chord}	compression chord modulus of elasticity
F^{cu}	ultimate compression strength
P^{max}	maximum measured force
A	cross-sectional area of specimen
$\Delta\varepsilon$	difference between strain points of averaged axial strain measurement
$\Delta\sigma$	difference between applied tensile stress between defined strain points
ε_u	strain at failure
ε_1	axial compression strain at strain measuring position 1
ε_2	axial compression strain at strain measuring position 2
B_y	percent bending criteria

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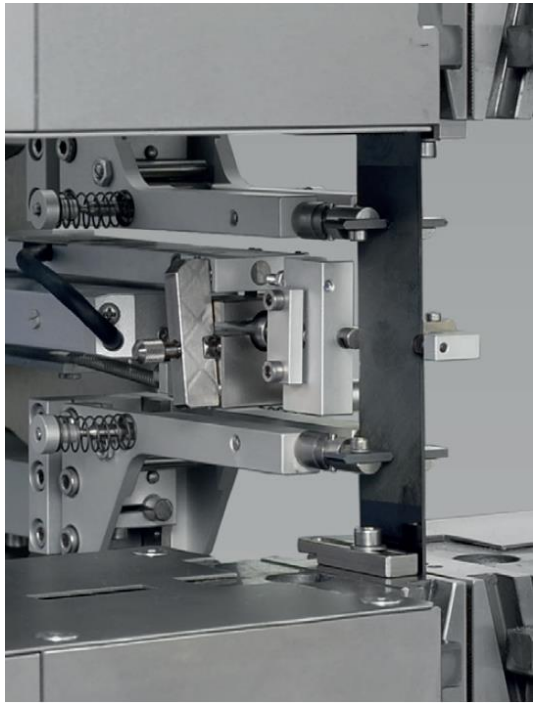
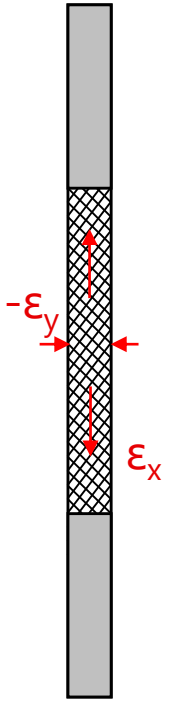
The tension test with ±45° laminate is a simple in-plane shear test. Using V-notched specimens both, in-plane and out-of-plane shear properties can be obtained.

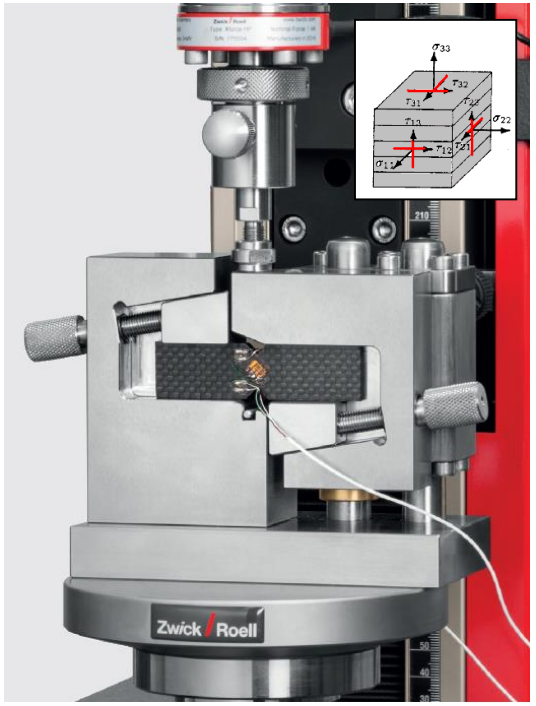
Tension test with ±45° laminate





ASTM D 3518	ISO 14129

Shear test with V-notched specimen

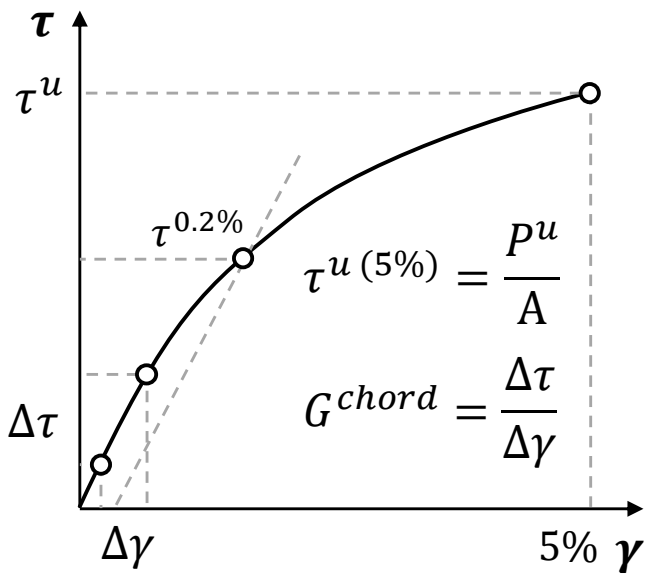


V-notched beam (Iosipescu)

ASTM D 5379

V-notched rail shear

ASTM D 7078



$$\tau = \frac{P}{A}$$ (ASTM D5379) (ASTM D7078)

$$\gamma = |\varepsilon_{+45}| + |\varepsilon_{-45}|$$

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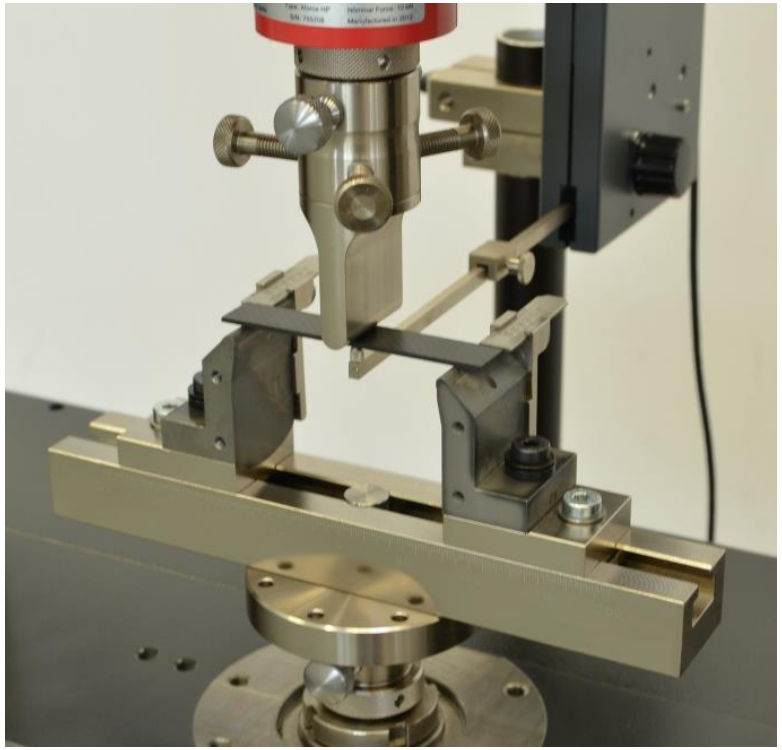
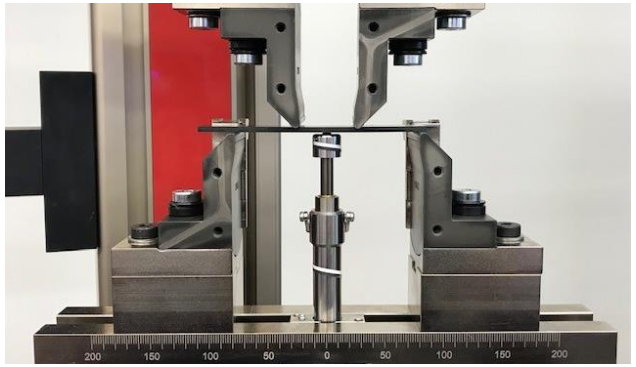
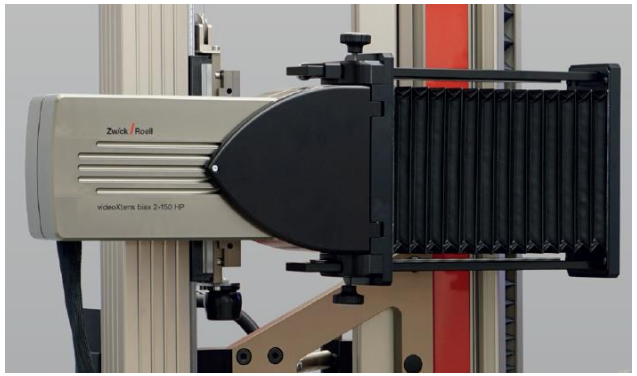
High quality tools and transducers are available for 3- and 4-point flexural tests at ambient and non-ambient temperatures.



3-point flexure test





4-point flexure test middle: deflection measurement with displacement transducer T25
right: deflection measurement with videoXtens and plunger

ISO 14125	EN 2562	EN 2746	ASTM D 7264	ASTM D 790	ASTM D 4476	ASTM D 6272

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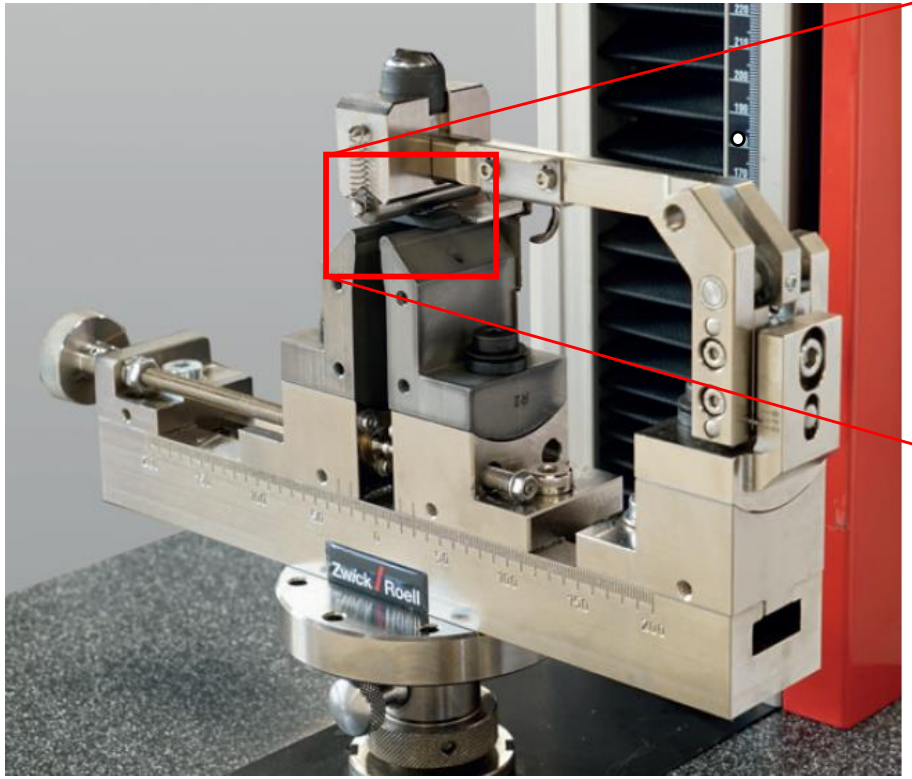
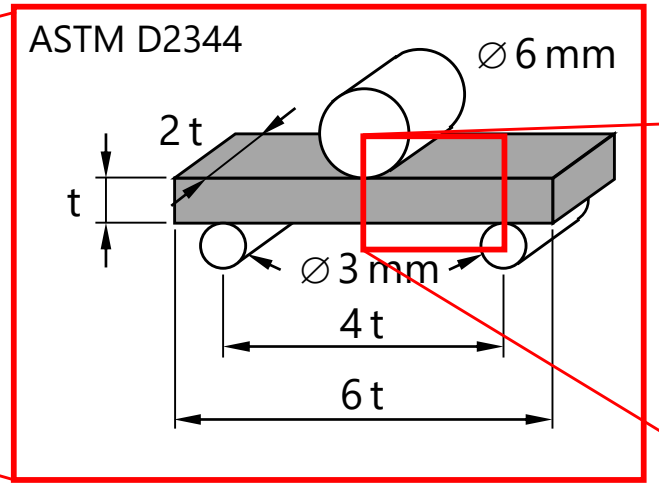
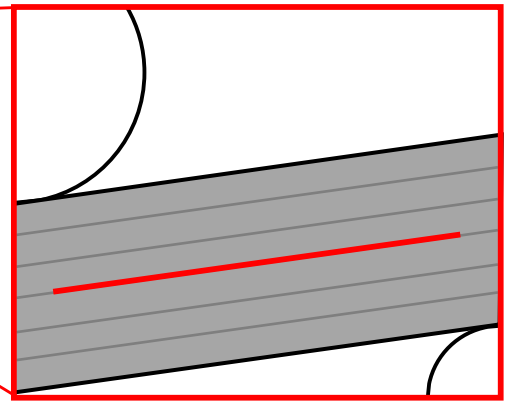
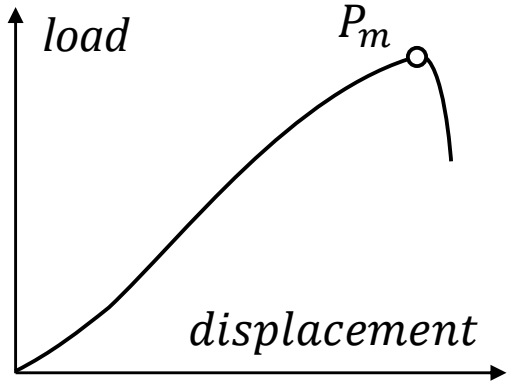
The ZwickRoell ILSS fixture with easy-to-set support distance is ideal for testing laminates with variable thicknesses.





deformed with interlaminar shear failure





$$F^{sbs} = 0.75 \times \frac{P_m}{b\ h}$$

F^{sbs}	short-beam strength
P_m	maximum applied load
b	specimen width
h	specimen thickness

ISO 14130	EN 2377	EN 2563	ASTM D 2344

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ZwickiLine and ProLine machines offer good quality and standard functionality that meets many applications. AllroundLine machines were designed to meet the highest requirements.

ZwickiLine

easy to operate single column load frames for loads up to 5 kN

ProLine

for tests that do not require complex sensor equipment

AllroundLine – Table Top

- very light and flexural stiff
- for loads up to 150 kN
- optionally with two test areas
- support legs to position test area at optimal operator height

AllroundLine – Floor Standing

- four guide columns for most accurate alignment of test axis
- for loads from 100 kN to 1200 kN
- optionally with two test areas
- tension-torsion machines available

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ZwickRoell has developed a modular system for ambient and non-ambient testing, covering 21 methods and about 120 test standards

Testing in large temperature range (depending on test setup)

Testing at ambient temperature

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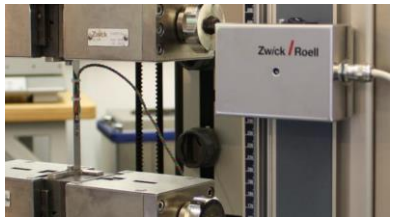
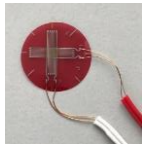
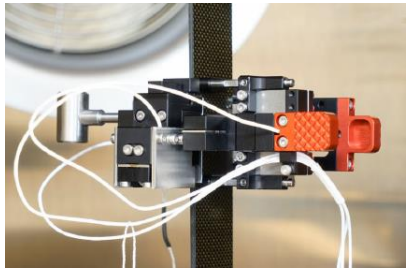
ZwickRoell offers a comprehensive range for strain and deflection measurement for composite testing.

Strain Measurement

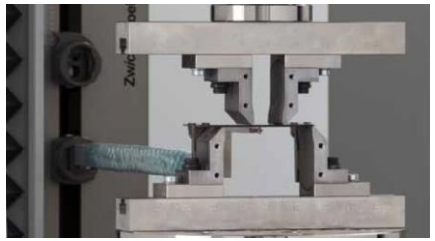
- Contact
  - Fixed
    - Strain gages
  - Detachable
    - Clip-on
    - Automatic sensor arm
- Non-contact
  - Optical

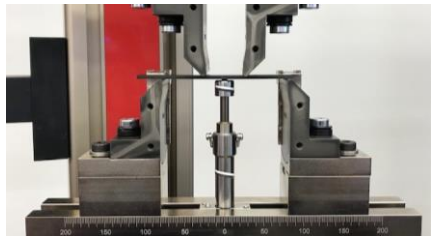






Deflection (flexure)





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When choosing a suitable measurement system you need to verify the necessity for biaxial strain measurement, deflection and the need for non-ambient temperature testing.

Strain or Deflection Measurement System	Ambient Temperature			Non-Ambient Temperature		
	ε_{axial}	$\varepsilon_{transverse}$	deflection	ε_{axial}	$\varepsilon_{transverse}$	deflection
strain gages (setup boxes or universal amplifier) *	x	x	-	x	x	-
axial clip-on extensometer 5025-1 **	x	-	with plunger	x	-	with plunger
biaxial clip-on extensometer biax 2501-1 **	x	x	-	x	x	-
makroXtens II automatic sensor-arm extensometer	x	x	x	x	-	x
videoXtens biax 2-150 HP	x	x	with plunger	x	x	with plunger
displacement transducer T25	-	-	x	-	-	x

*
- one-time use only
- time consuming application
- may be damaged before ultimate failure
- often difficulties when bonding to thermoplastic composites

** extensometer must be detached before failure for specimens with highly energetic failure modes (e.g. tension in fiber direction)

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