Workshop on Materials for Collimators and Beam Absorbers

Experimental methods for material measurements at high strain-rate

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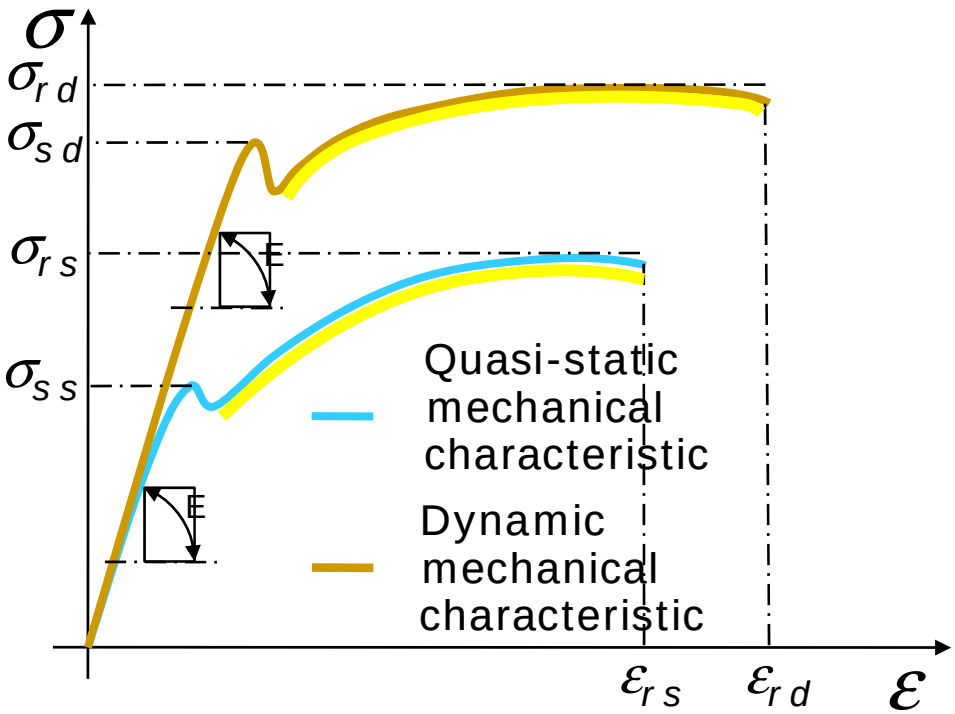
Dynamic effects on material behavior

Stress-strain characteristic and the effect of strain-rate on the mechanical behaviour of a material

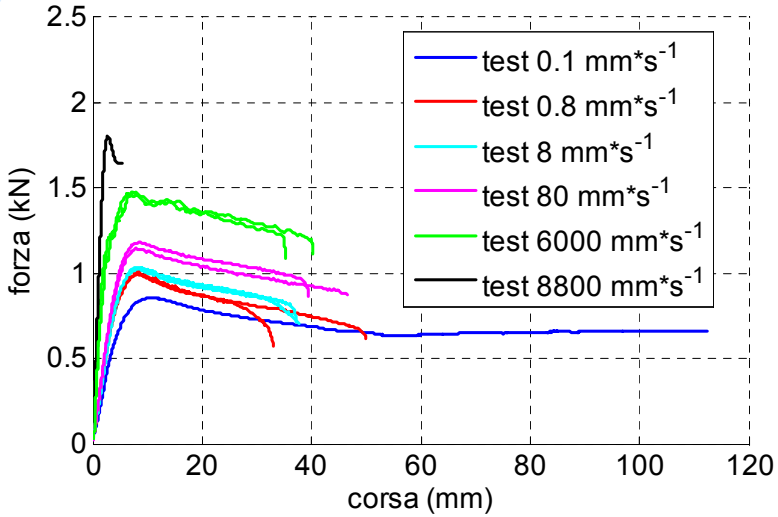


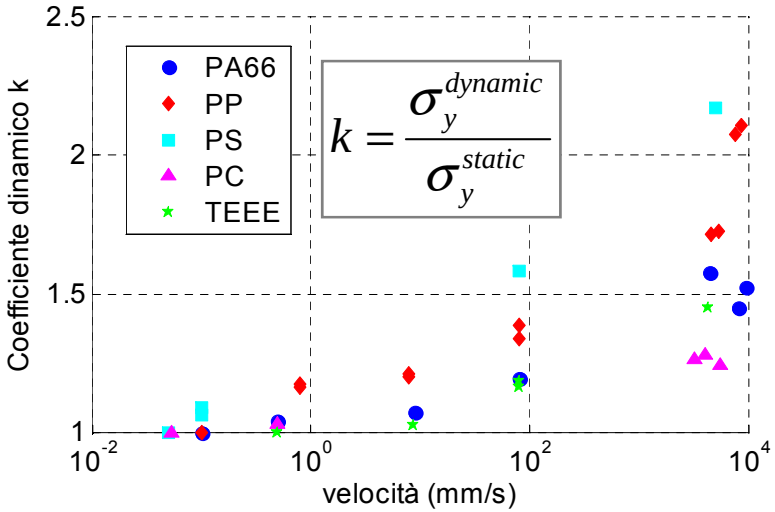
- Variation in yield strength
- Variation in failure strength (ultimate tensile strength)
- Variation in elongation at failure
- Different work-hardening behaviour

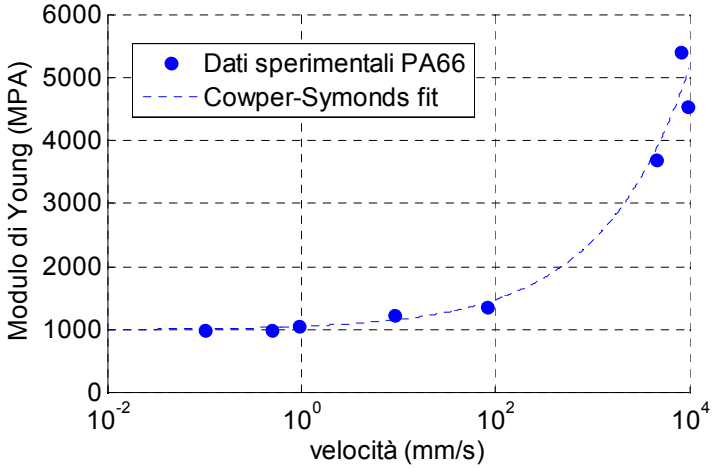
For many materials, strain-rate has negligible effect on the elastic modulus

Strain-rate effect: some experimental results

PP, mechanical characteristics



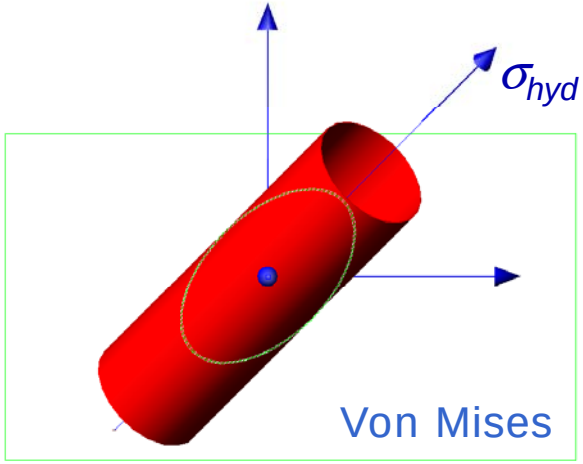


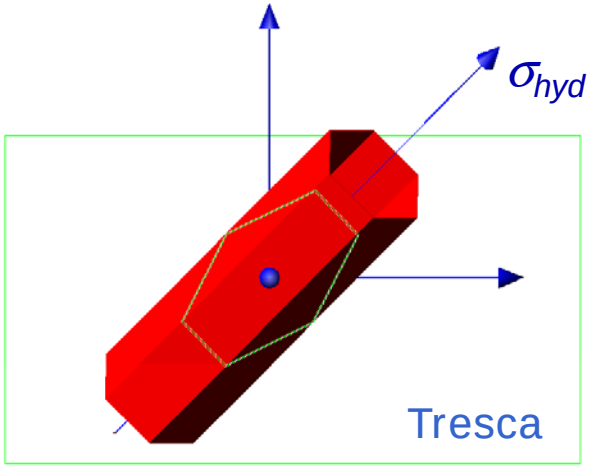


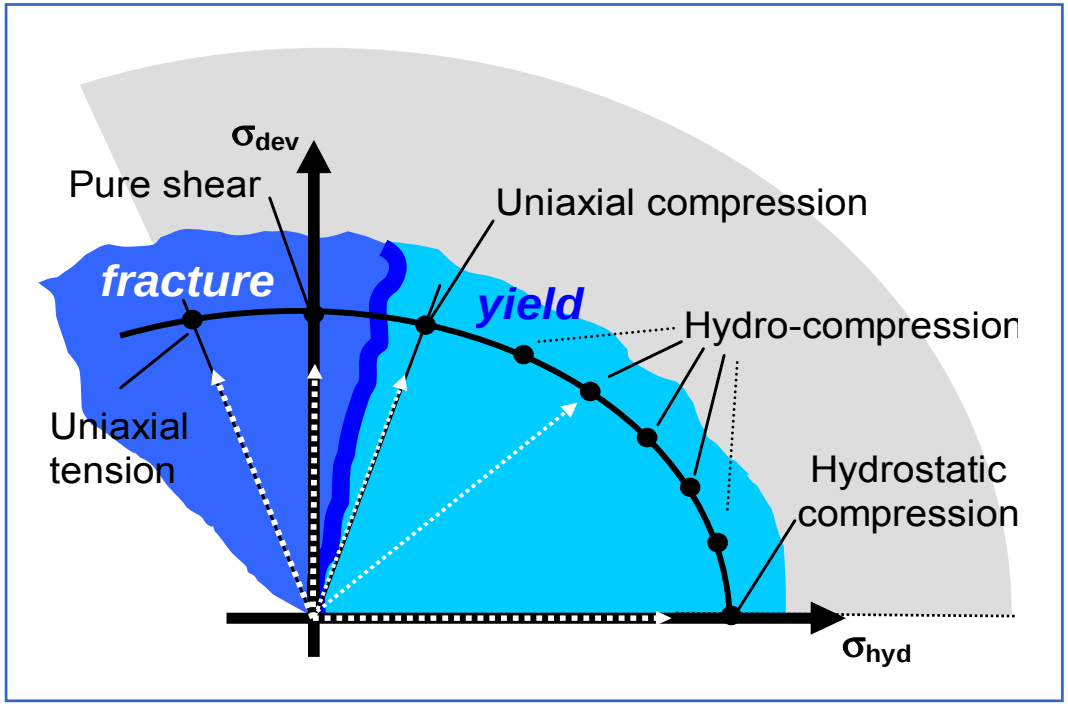
- Different classes of polymers tested: PP, PA6, TEEE, PS, PC, EVA…

Multiaxial behavior (plastics, foams…)

As it is well known plastics and cellular materials yield is not independent on the hydrostatic component of stress

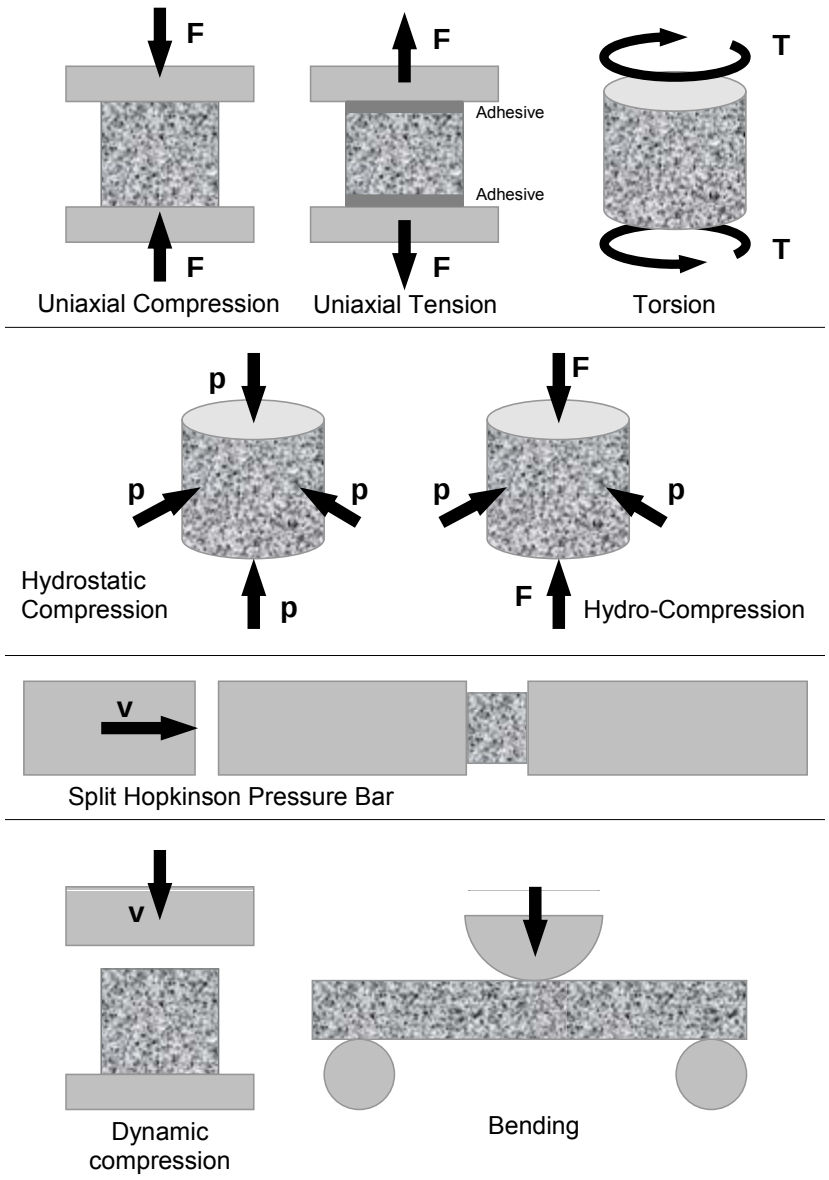


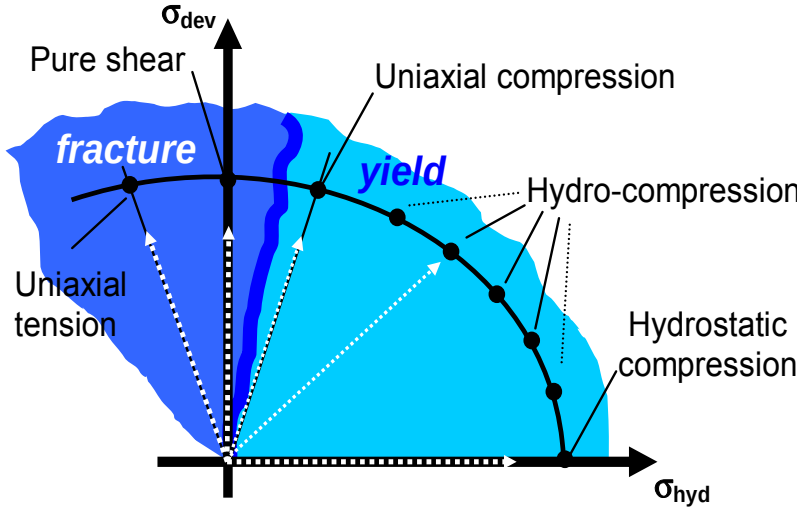




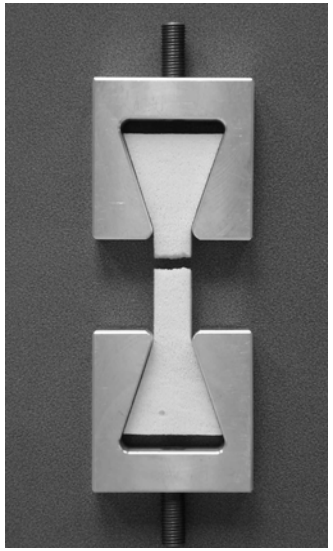
Therefore, the plastic collapse condition cannot be characterized from the result of a single (uniaxial) test, having a given ratio of hydrostatic/deviatoric stress components, but it is necessary to perform several tests with different combinations of deviatoric and hydrostatic stress components

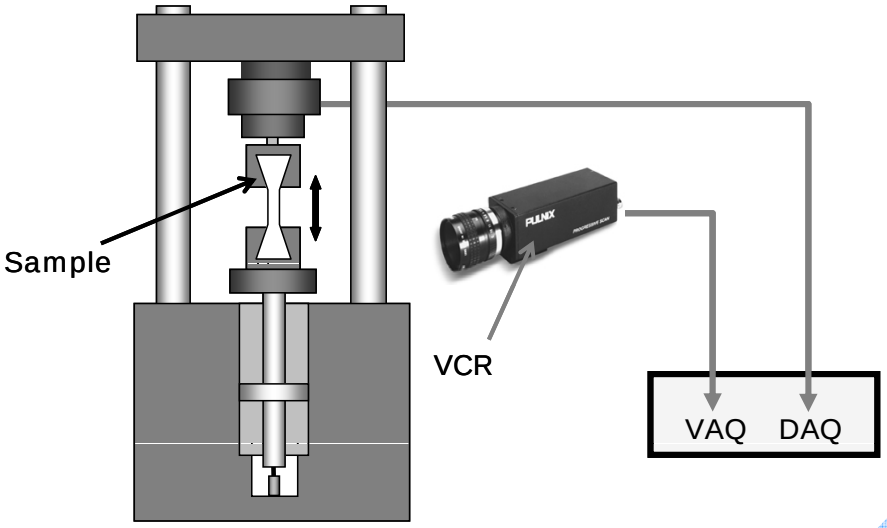
Testing methods



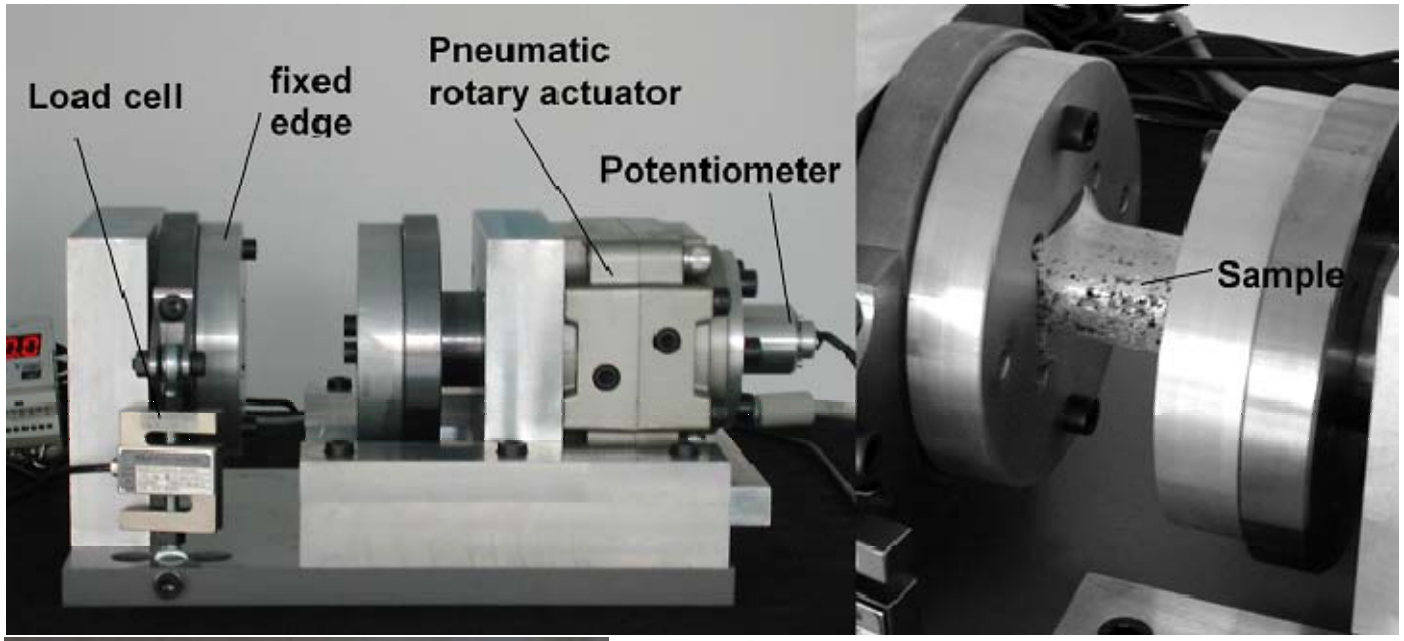


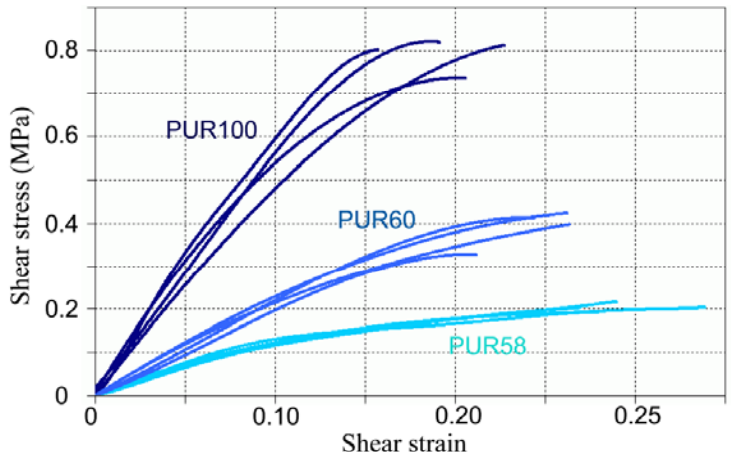
Uniaxial tension test





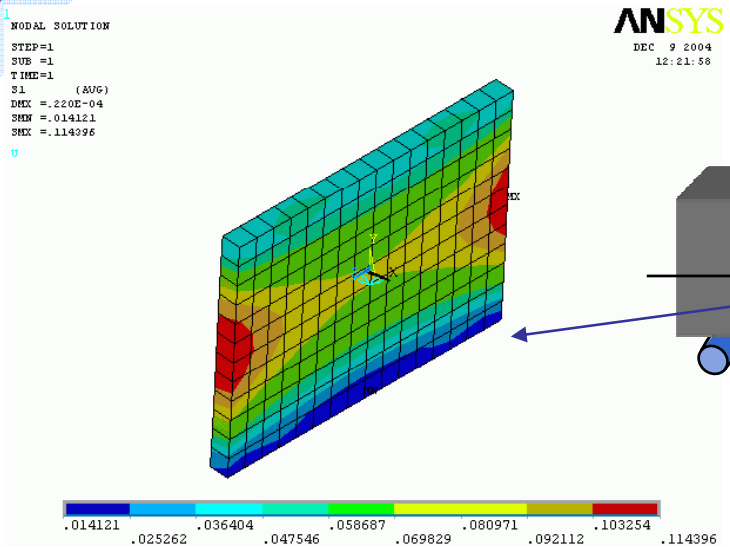
Shear: torsion test

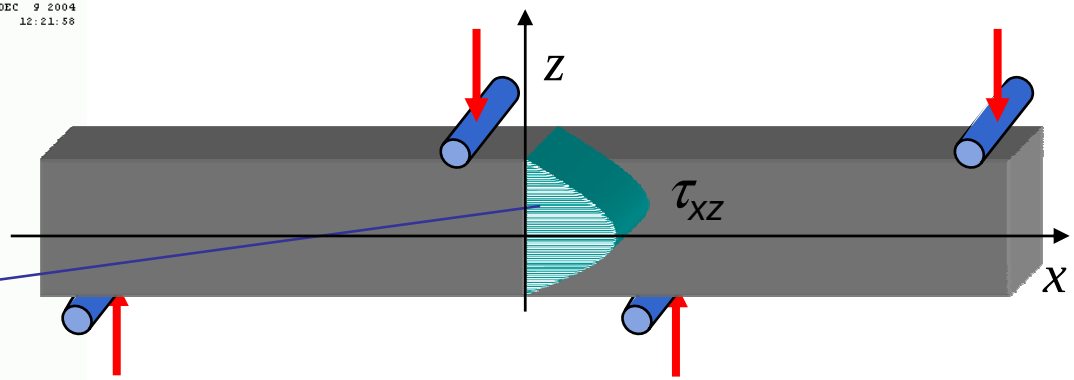




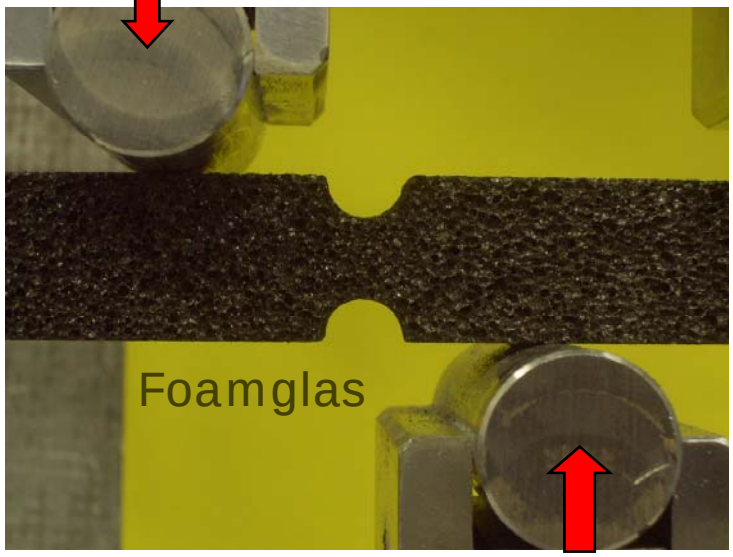
Torsion loading test rig (shown with an aluminum foam sample mounted on it)

Shear: 4-point asymmetrical tests



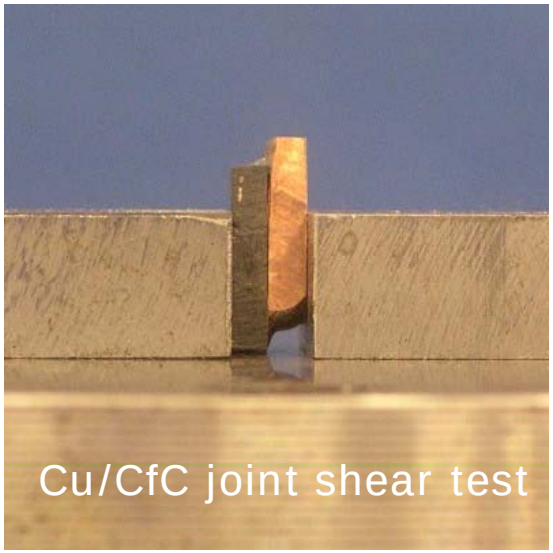


- Used for the mechanical characterization of ceramics, and ceramics composites (CfC's) according to ASTM C1469 standard



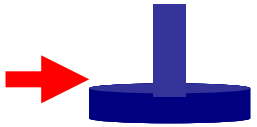
Shear strength of joinings

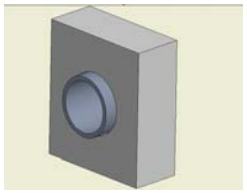
Offset single-lap

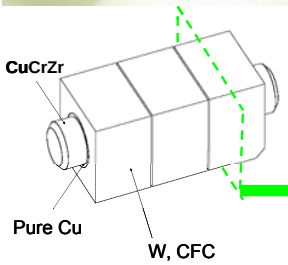


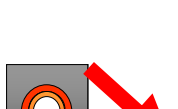
*CFC/Cu/CuCrZr and W/Cu/CuCrZr joints for ITER

Shear/compression

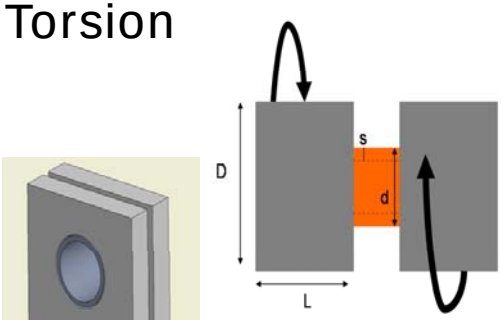




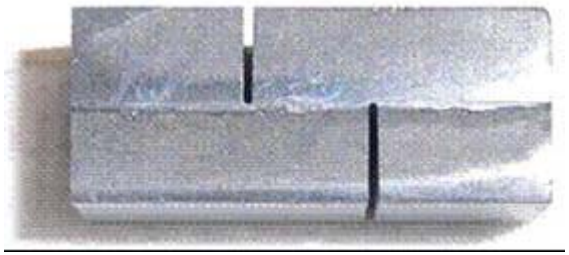




Torsion

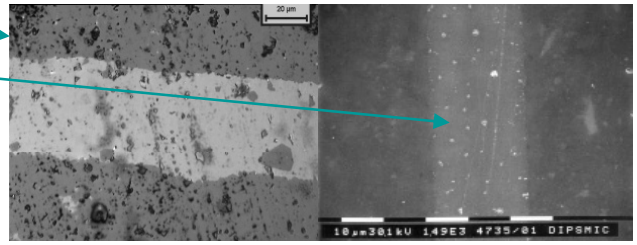


Double-notch (ASTM C1292)

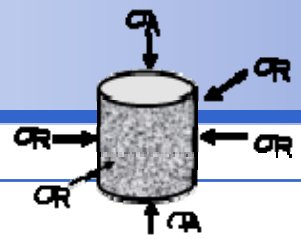


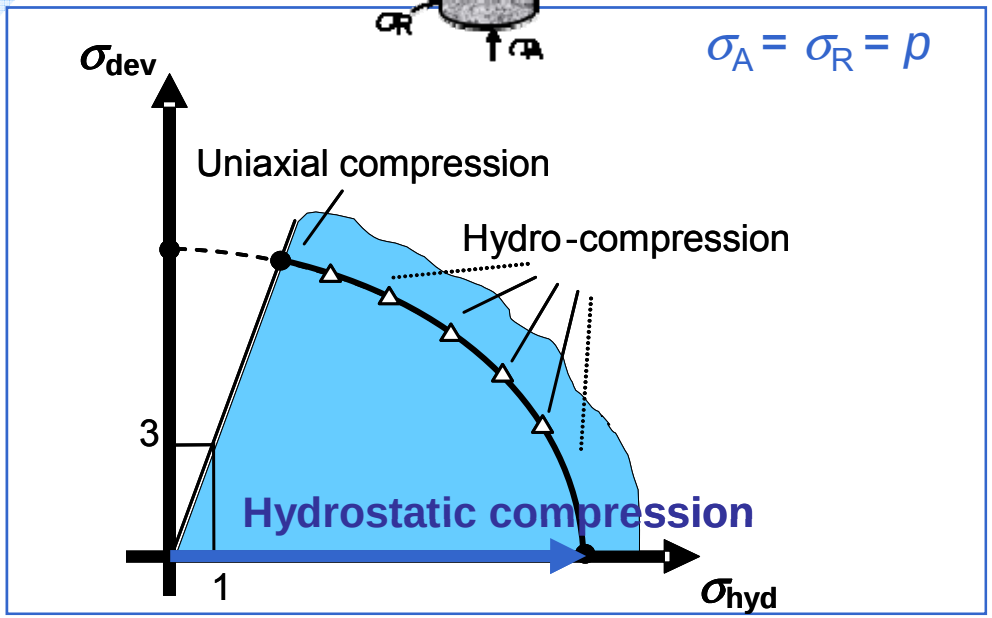
SiC joined by:

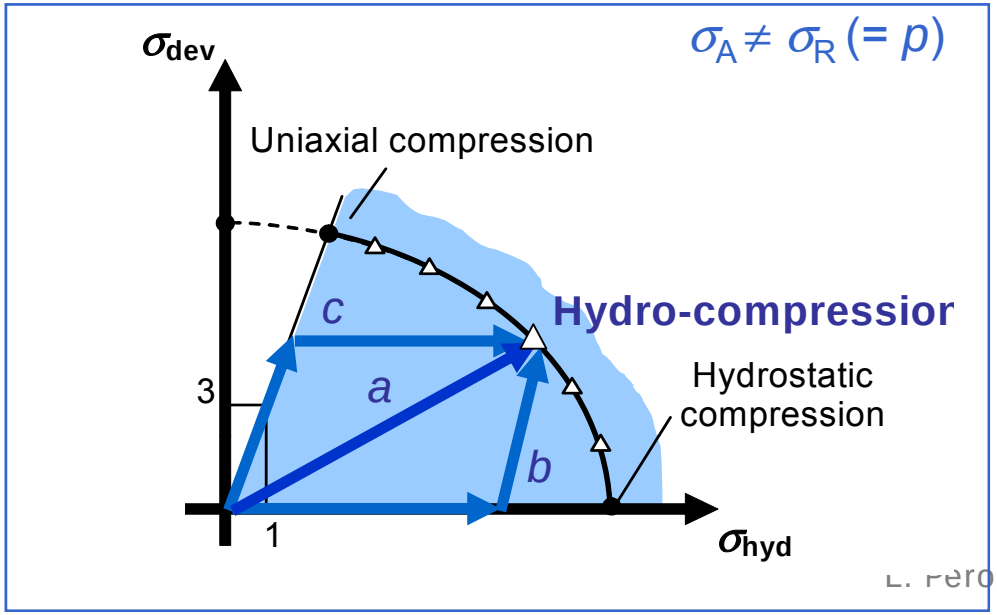
- Silicon
- Glass

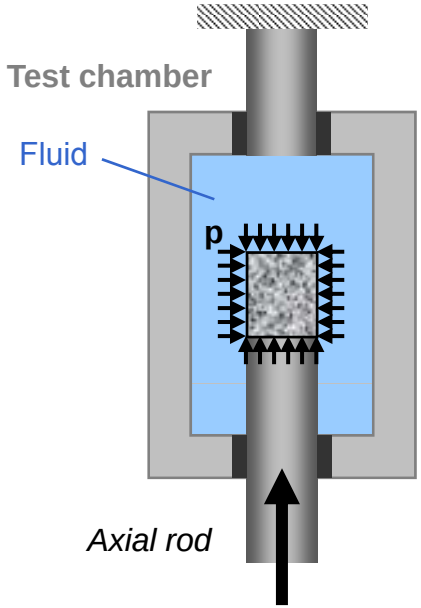


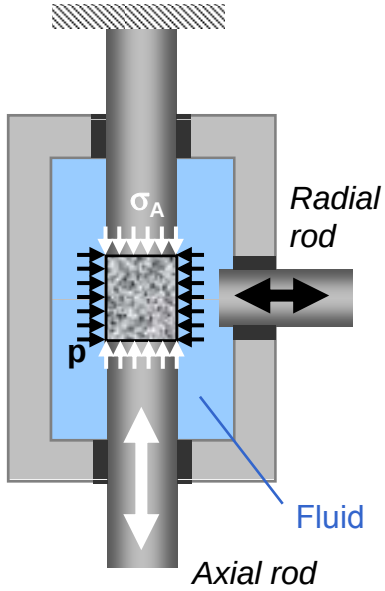
Hydrostatic tests



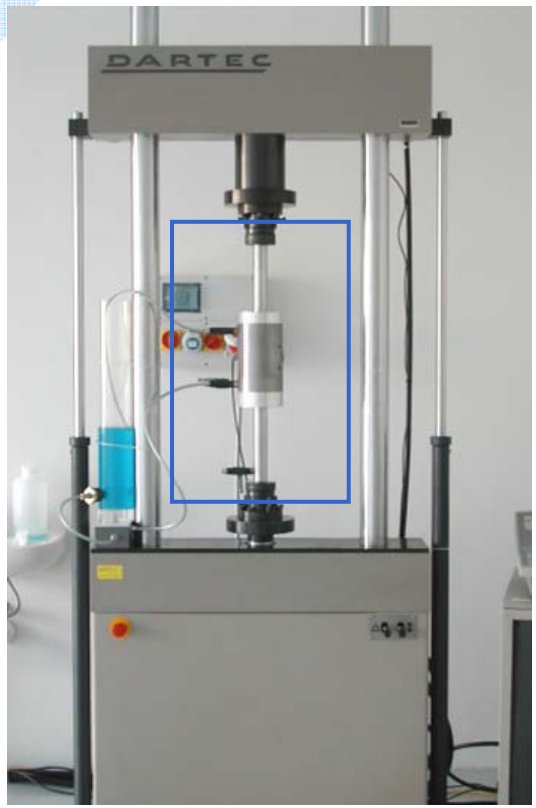




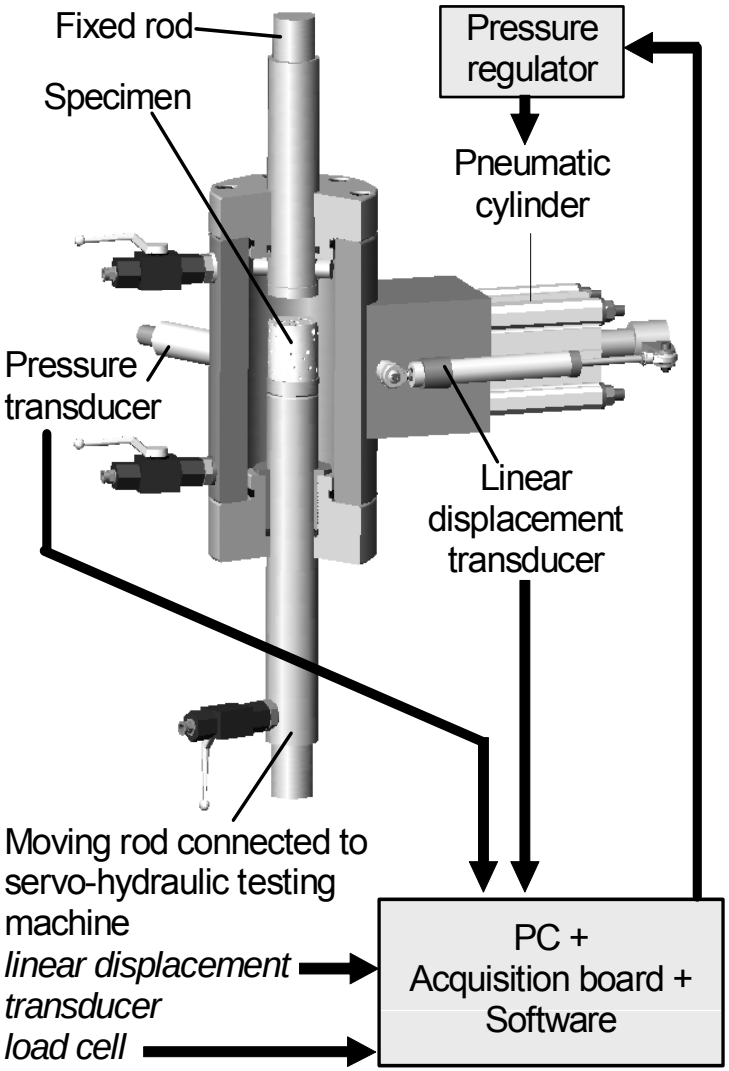




Hydrostatic and hydro-compression test



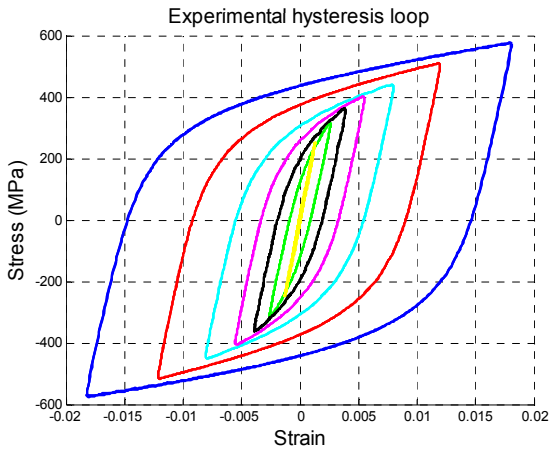
Hydrostatic (compression)

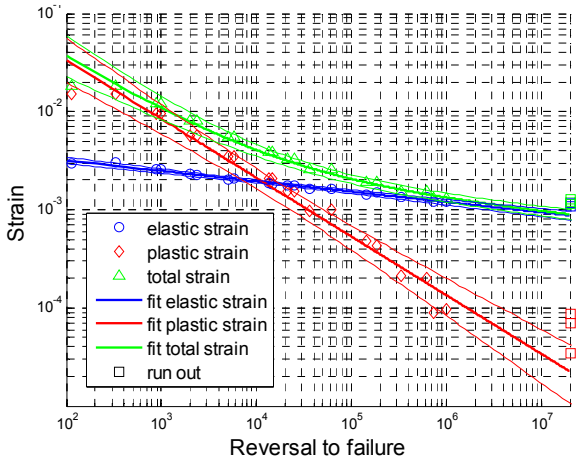


Hydro-compression

Fatigue loading

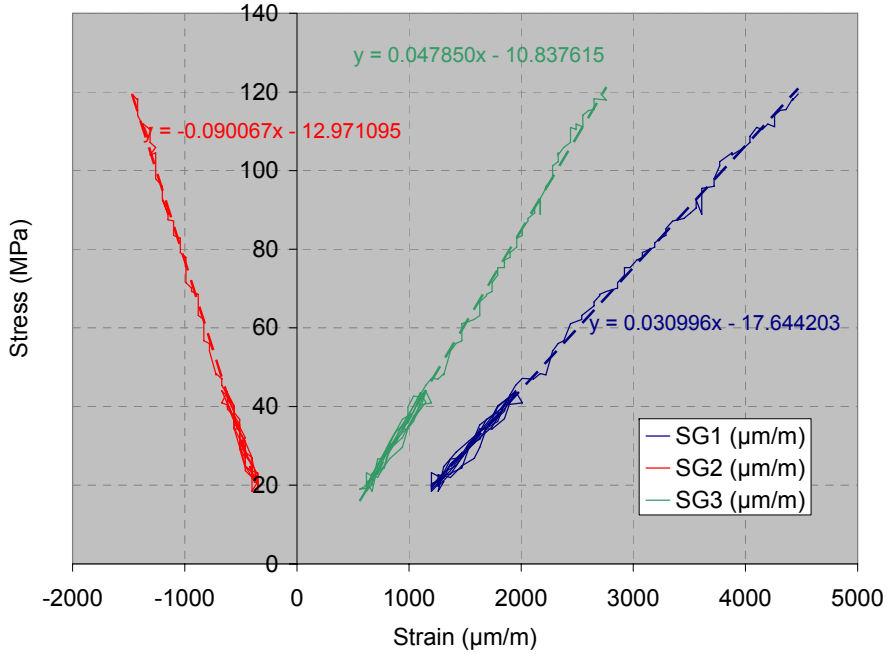
- Stress-life and strain-life approach
- Rotating bending (metals), plane bending (polymers, composites) high-cycle fatigue
- Tension/compression low-cycle/high-cycle fatigue (evaluation of the hysteresis of the material)

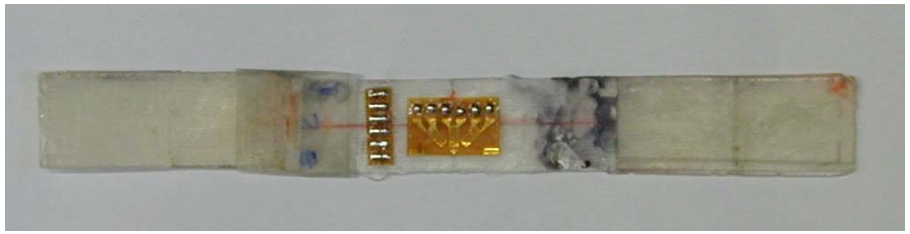




Composites

- For orthotropic materials like most composites, tests at different loading angles are required to obtain the different moduli (in-plane E_{11}, E_{22}, G_{12}) and Poisson's coefficient (ν_{12})
- For unbalanced layered composites, bending tests are also required
- Impact tests are also performed to measure dynamic properties energy absorption capability



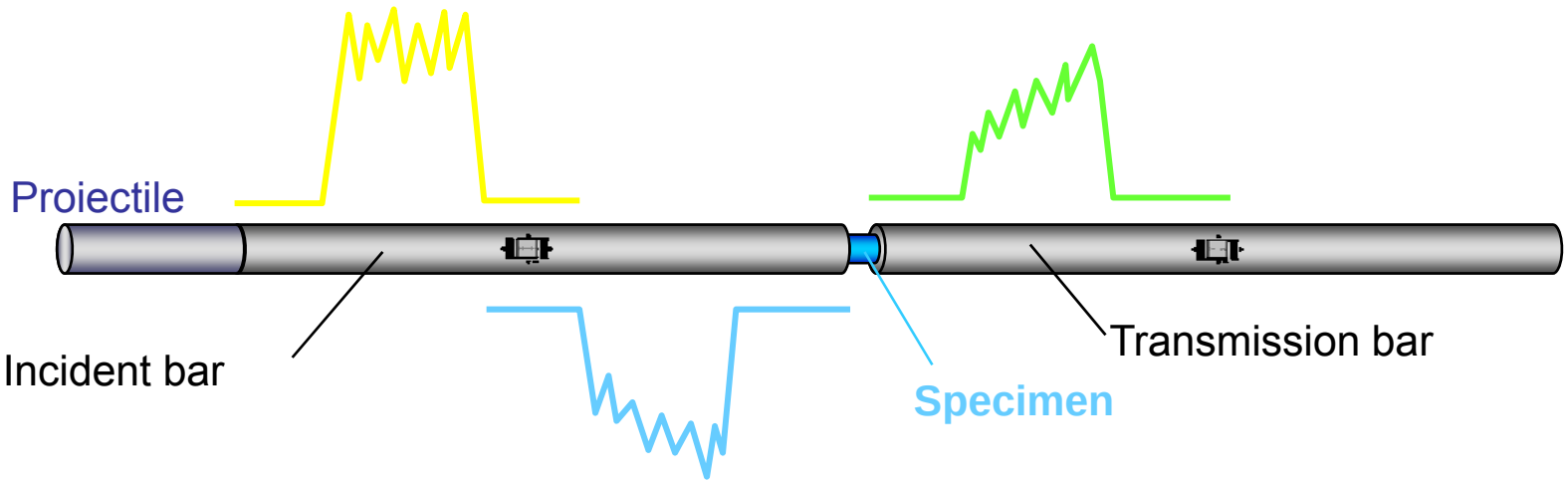


GFRP sample with rosette to measure strain in different directions

The Split Hopkinson Pressure Bar (SHPB)

Operating principle

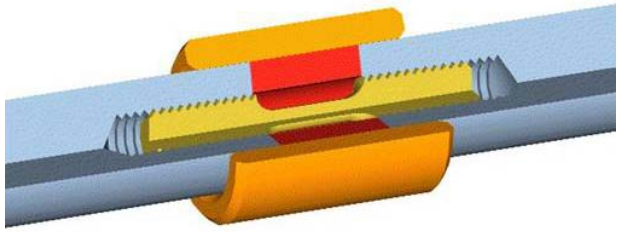
- The projectile hits the incident bar generating a compressive wave train
- The wave train propagates at the speed of sound in the bars material and reaches the specimen, then:
  - It is partly reflected
  - Partly crosses the specimen and goes through the transmission bar
- The reflected and transmitted waves are measured
- By reconstruction based on the two signal the dynamic mechanical characteristic is obtained



The Split Hopkinson Pressure Bar (SHPB)

- Split Hopkinson Pressure Bar (SHPB, compression test)
- Split Hopkinson Tensile Bar (SHTB, tensile test)

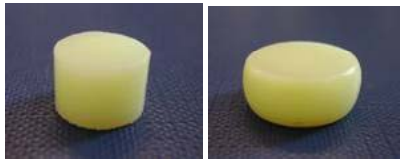
Tensile specimen

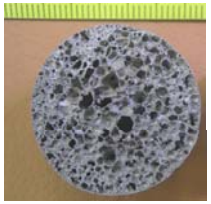


Steel sheet

Compression specimen

Bulk adhesive

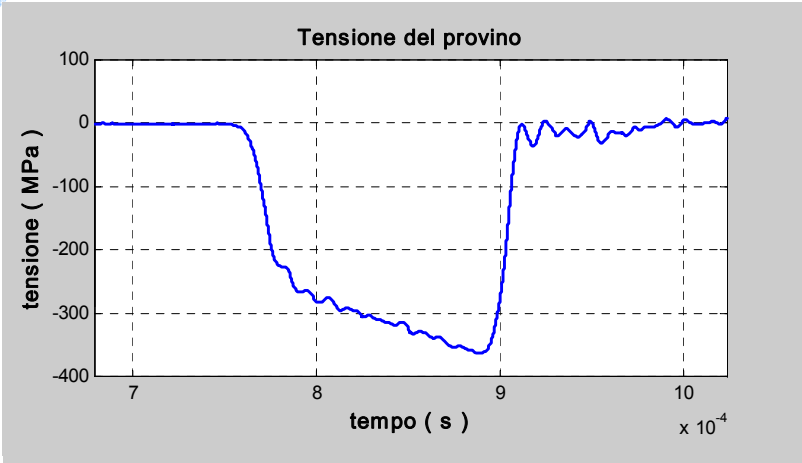




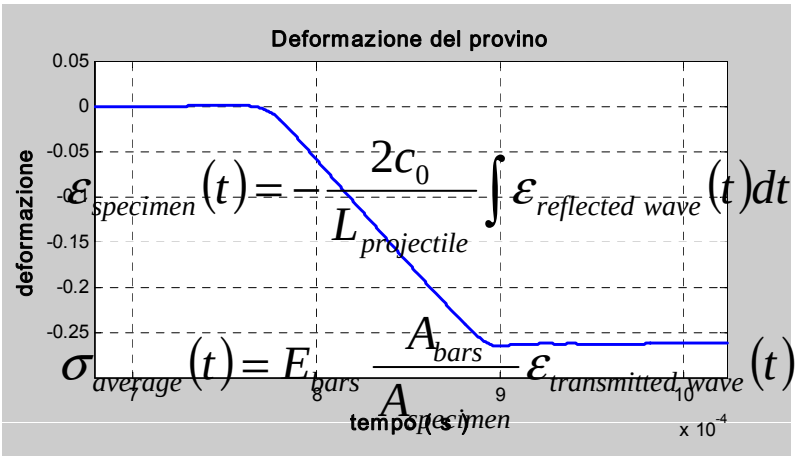
Aluminum foam

Bulk adhesive

Determination of the stress-strain characteristic

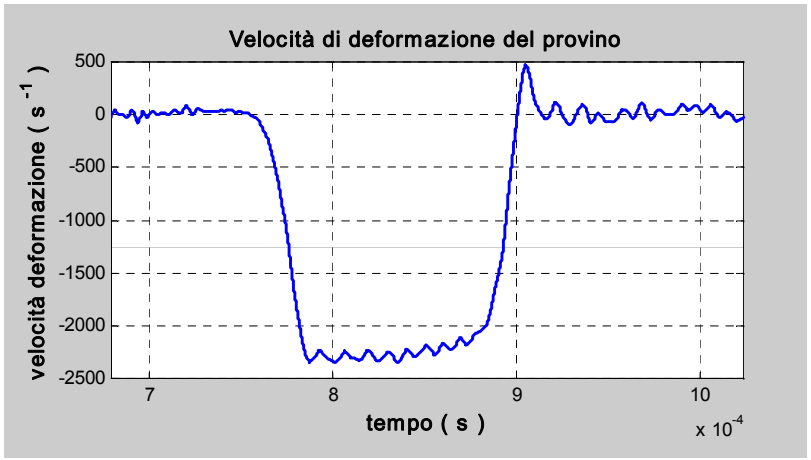


- Time history measurement of:
  - Average stress (specimen)
  - Strain-rate (specimen)
  - Strain (specimen)
- Signals synchronization
- Evaluation of the stress-strain characteristic

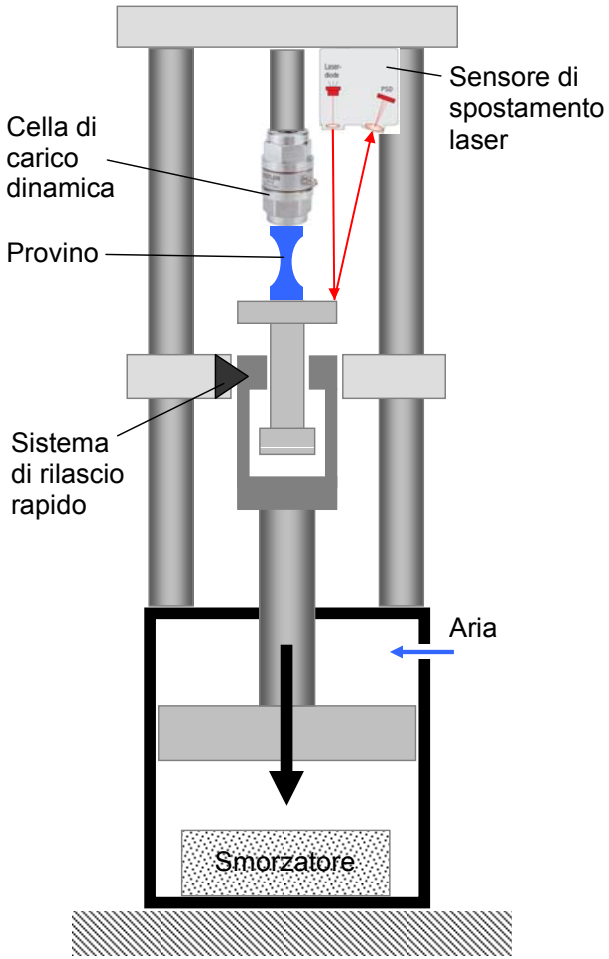


$$\varepsilon_{specimen}(t) = -\frac{2c_0}{L_{projectile}} \int \varepsilon_{reflected\ wave}(t)dt$$

$$\sigma_{average}(t) = E_{bars} \frac{A_{bars}}{A_{specimen}} \varepsilon_{transmitted\ wave}(t)$$



Dynamic tensile equipment: FasTENS



To cover the speed range from 1 to 10 m/s, in tensile loading, in between the hydraulic systems and the SHPB, a special fast tensile equipment, pneumatically actuated, has been developed (**FasTENS**).

Dynamic compression: ComPULSE

- Pneumatically actuated
- Maximum speed up to ≈15 m/s
- Maximum available energy ≈3 kJ
- Load measurement with piezoelectric load cells, maximum load 220 kN
- Stroke measurement with laser transducer (Keyence)
- Suitable also for tensile, bending, and other tests using special fixtures

Low / high temperature testing

- A climatic chamber coupled with the ComPULSE equipment, was developed for dynamical tests down to -–40°C (will be further improved to be pushed down to -80°C) and up to 100°C
- The sample (or component) can be conditioned but also tested at various controlled temperatures

Concluding remarks

- The mechanical characterization of materials is one of the first steps in the design of high performance structures
- The spectrum of mechanical tests available is very large, to cover many possibility of loading, even far beyond established standard
- Custom testing solutions are routinely developed, and will be likely to be developed for innovative and advanced materials
- In most cases a single type of test is not sufficient to describe in details the properties and behaviour of an advanced material or composite

Experimental methods for material measurements at high strain-rate

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Thank you for your attention!