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SERVICES FOR RELIABILITY

Mechanical damage monitoring on aluminum freestanding thin films used for MEMS applications

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Outline

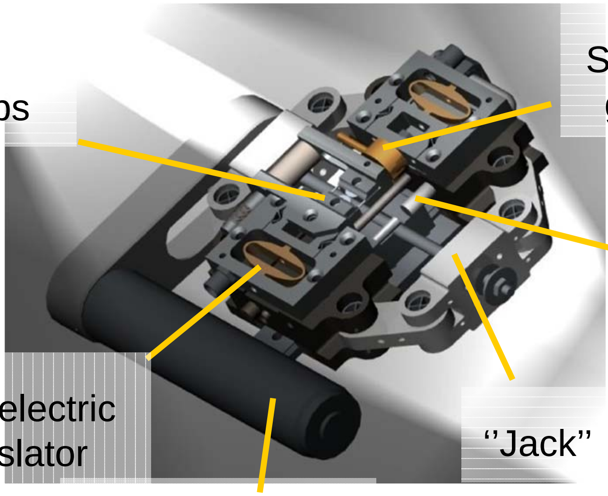
- Scope of the study
- Description of the microtensile apparatus and tensile specimens
- Theory on the damage of material
- Description of the mechanical and electrical methods for measuring damage of material
- Results

Scope of the study

- The mechanical functions of MEMS (sensors or actuators) are often insured by moveable thin films (thickness of a few micrometres)
  - ✓ Dimensioning micro-systems requires relevant data on the mechanical behaviour (elastic parameters and yield stress)
  - ✓ The reliability assessment requires more data on the fatigue and damaging laws
  - ✓ Some applications require large deformations (flex-IC) with plastic behaviour and substantial damaging

- Two methods are developed here for the characterization of damage of freestanding thin films:
  - ✓ Mechanical characterization
  - ✓ Electrical characterization

The microtensile apparatus



Schematic (INPG)

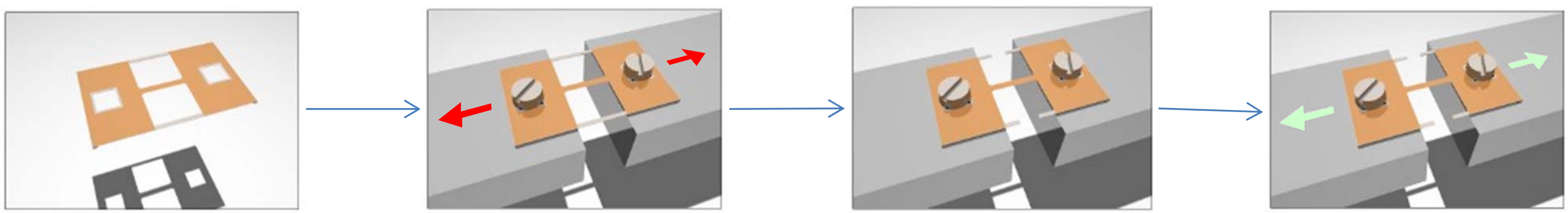
Characteristics	
• Set-up stiffness • Displacement rate • Maximal Load Charge	150kN/m 0.01 to 50µm/s 20 N

Measurement	**Resolution**	**Data range**
• Force : 3 mini load cells	∞	10^{-4} to 400N
• Displacement : 2 indpt sensors	1.25nm	A few nm to 6mm

- Characterization of the stress-strain relationship of thin coatings
- Strain measurements is a key issue --> overcome by the use of interferometry technique

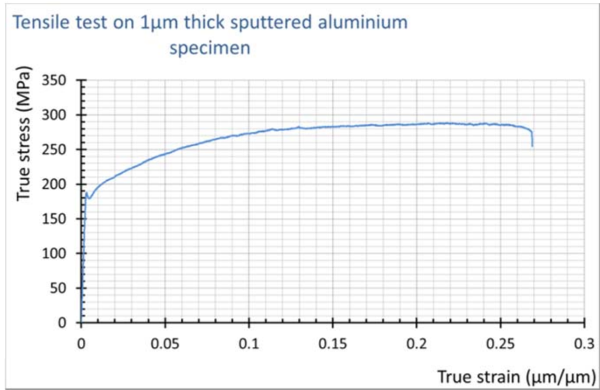
The microtensile apparatus

Testing flow :



- The specimen is fastened into grips to prevent any awkward slipping
- After cutting the frame, the grips are moved away from each other
- The load and displacement are monitored (converted in a stress-strain curves)
- Post-test analysis : fractography and geometrical parameters

Elastic-Plastic uniaxial behaviour:
Young's modulus (E), yield stress (Y), strain-hardening, ultimate elongation and strength (ε_u, σ_u).



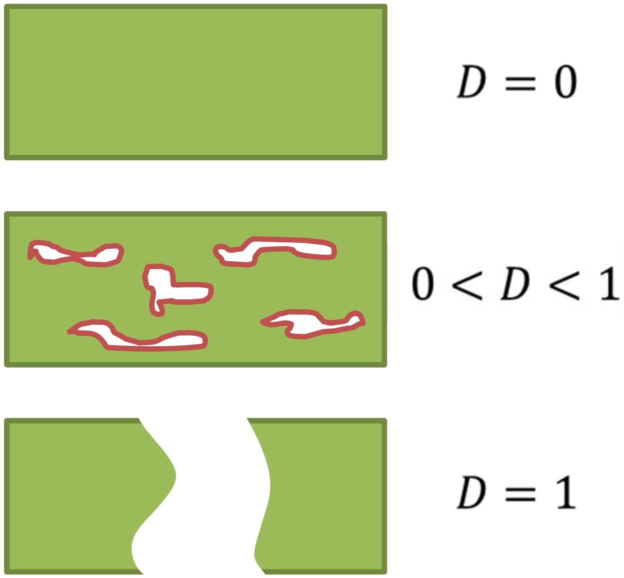
Theory of damage and mechanical characterization :

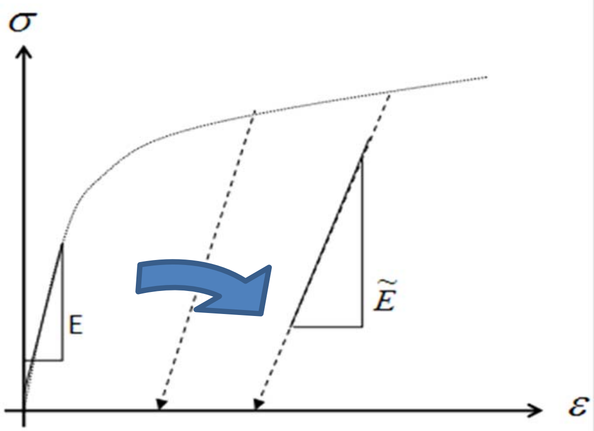
J. Lemaitre and J.L. Chaboche, Mécanique des Matériaux Solides (2nd éd.) (1988)

- The damage variable D has been introduced by Lemaitre[1] in order to characterize the damage of material.
- $D \rightarrow 0$ for a virgin material and $D = 1$ for a broken material
- According to Lemaitre, the Young's modulus $\tilde{E}$ of a damaged material depends on the initial Young's modulus and D:

$$\tilde{E} = E(1 - D)$$

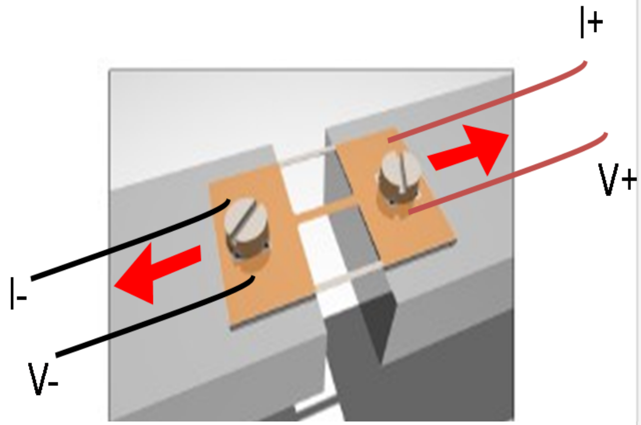
- A multicycle experiment with several loading and unloading is efficient for characterizing the evolution of D through the evolution of $\tilde{E}$

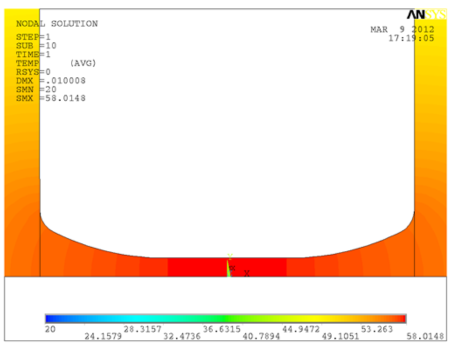




The electrical measurement of damage

- **Theory**:
  - ✓ The electrical resistance R depends on the resistivity ρ, section S and length L of the specimen:
  $$R = \rho \frac{L}{S}$$
  - ✓ Damage variable D is linked to the damage section $\tilde{S}$:
  $$\tilde{S} = S(1 - D)$$
  - ✓ The evolution of D is then linked to the evolution of the electrical resistance R.
  - ✓ **BUT**: the evolution of section is not only due to the evolution of D → variations due to the volume conservation in plastic deformation

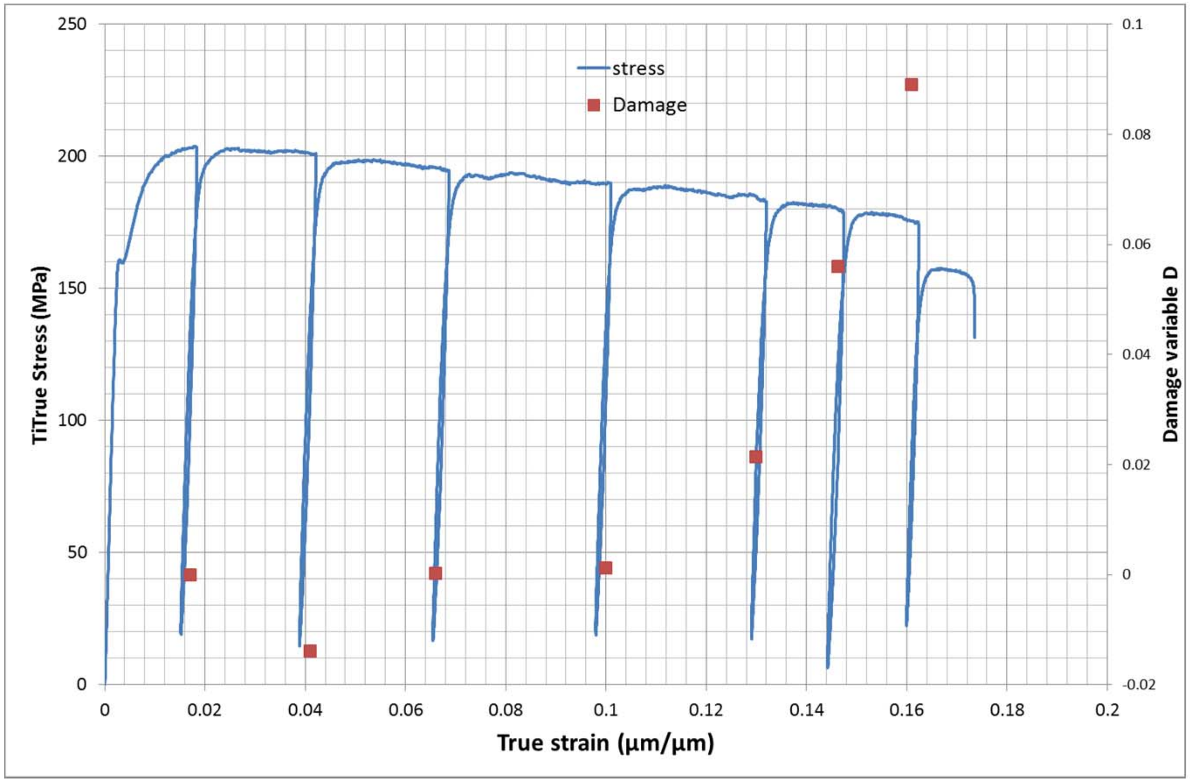




- **Electrical measurement**
  - ✓ A four-wires probe method have been used in order to avoid contact resistance measurement.
  - ✓ FEM simulation performed in order to ensure that the electrical measurement does not induce too high temperature

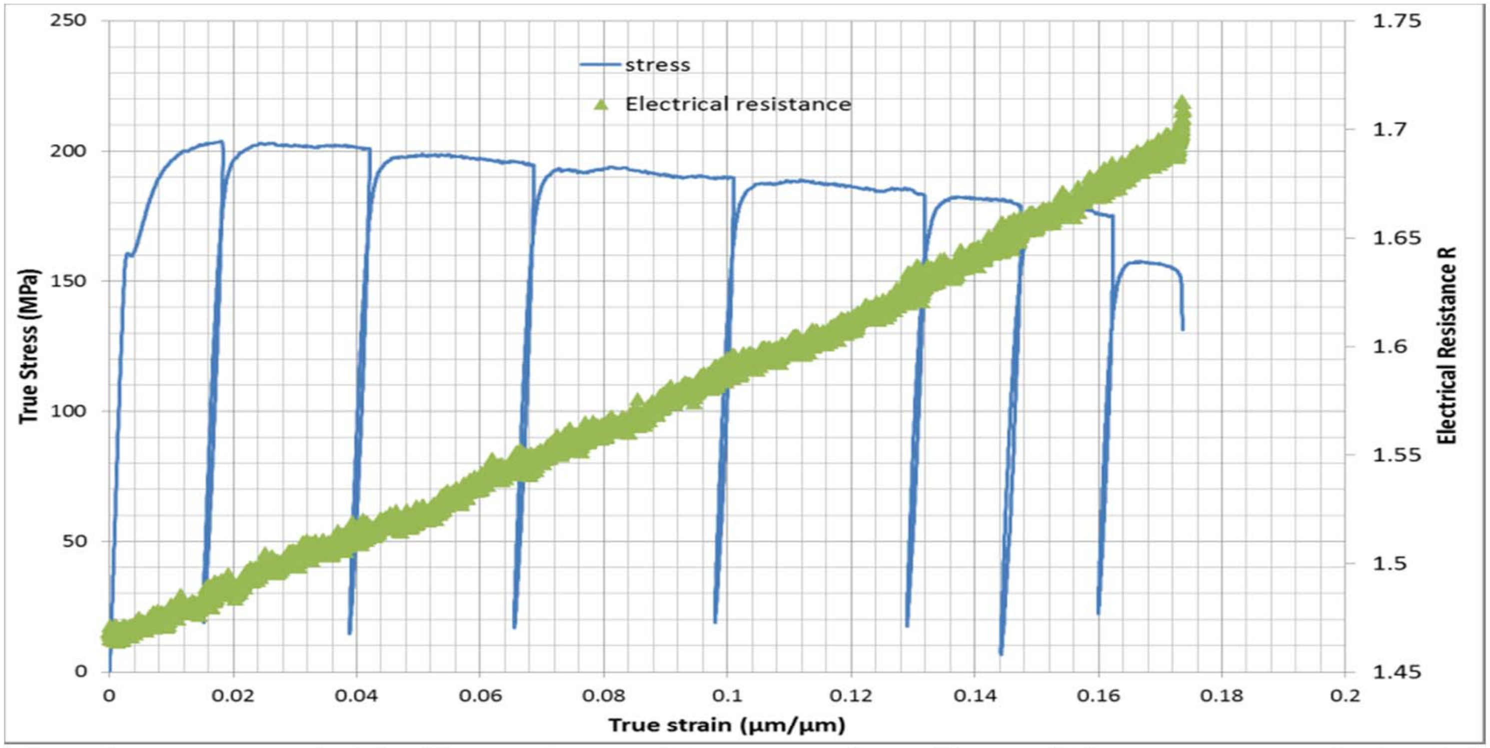
Results for mechanical damage:

- Multicycle experiment performed on Aluminium freestanding thin films.
- Observations:
  - ✓ While $\varepsilon < 0.1$, even if the stress falls, there is no damage in the material
  - ✓ From $\varepsilon = 0.1$ until failure, D increases fast.



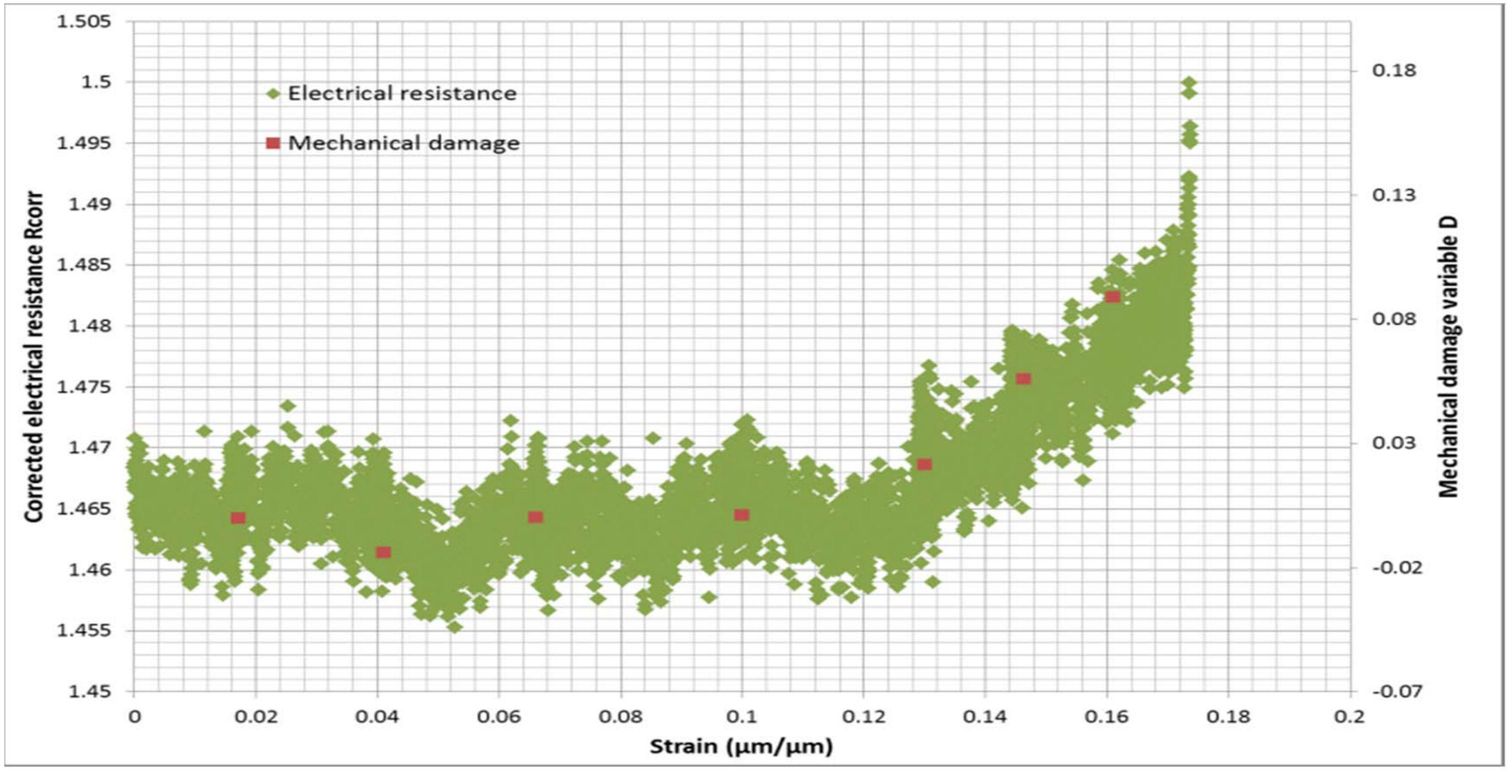
Looking only at the stress-strain curve lead to the conclusion that damage occurs from $\varepsilon = 0.0125$

Mechanical vs electrical measurements of damage



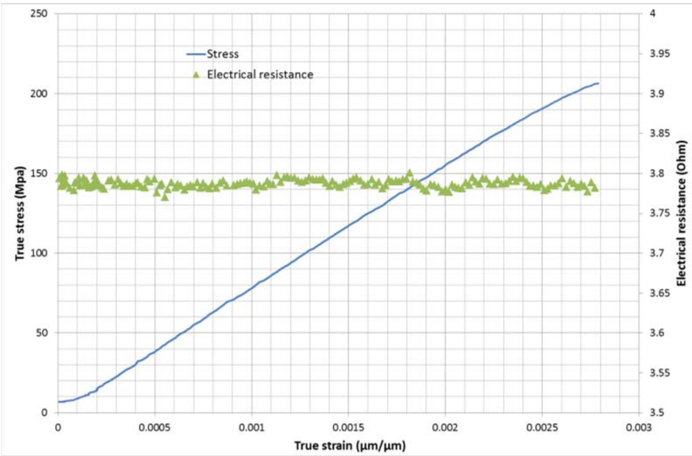
- The damage variable D can be written as a function of the measured electrical resistance R_{meas}.
- The evolution of R is linked to the evolution of section and length.
- R_{meas} must then be corrected in order to be only proportional to D.

Mechanical vs electrical measurements of damage

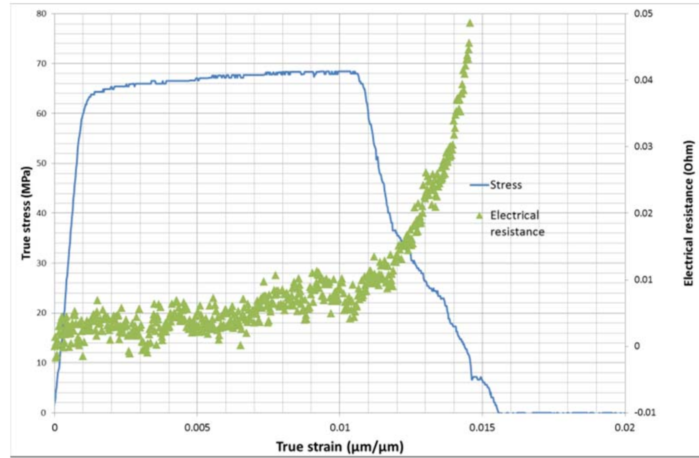


- Until $\varepsilon = 0.1$, from mechanical experiment $D = 0$ ➔ the evolution of R_{meas} is only due to geometrical effect which is linear.
- Subtracting this effect to R_{meas}, the evolutions of R_{corr} and D_{meca} are perfectly superposed.

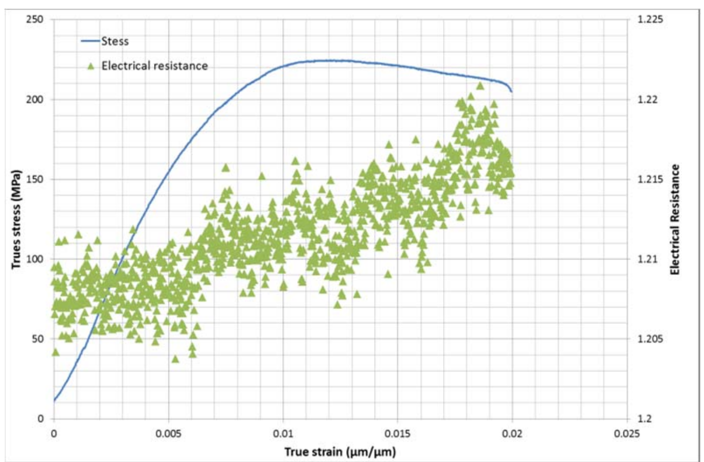
Influence of mechanical behaviour on the evolution of electrical resistance



Brittle gold specimen



Ductile gold specimen



Ductile aluminium specimen

Conclusion

- Stress-strain curves are needed to properly design MEMS devices. Specific apparatus and methods must be employed (microtensile test)

- But Fatigue and damages should also be investigated to properly estimate the reliability and lifetime of devices :
  - ✓ *The performances of a RF-switch are primarly linked to the stiffness of the moveable electrode, ie. to its apparent Young's modulus, ie. to the cumul of damage through multiple cycling.*

- Two methods have then been developed to characterize damage of freestanding thin films during a uniaxial tensile test :
  - ✓ The multicycle experiment is a method which gives accurate results but asks for particular loading and unloading.
  - ✓ The measurement of the electrical resistance is a new method that gives continue information on the damage level along with an monotonic uniaxial tensile test.

  → on-board monitoring of the damage level could be implemented at device level.