7. Strategies for different materials

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Load cycles for different material systems

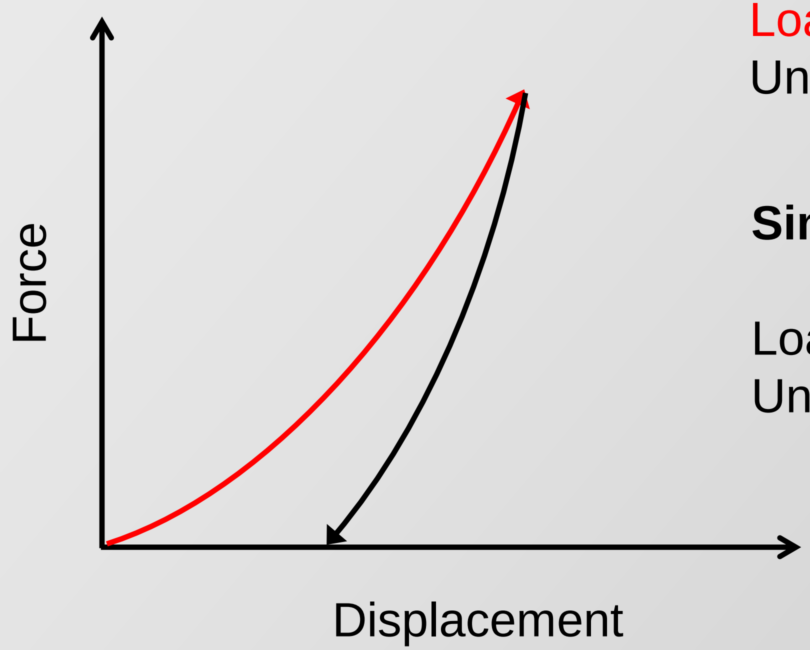
How will your material respond?

- elastic – plastic
- pile-up or sink-in
- time dependent, creep
- rough
- sticky

What do you want to measure?

- elastic properties
- plastic properties
- fracture properties
- dynamic properties
- qualitative or quantitative values

Hardness test



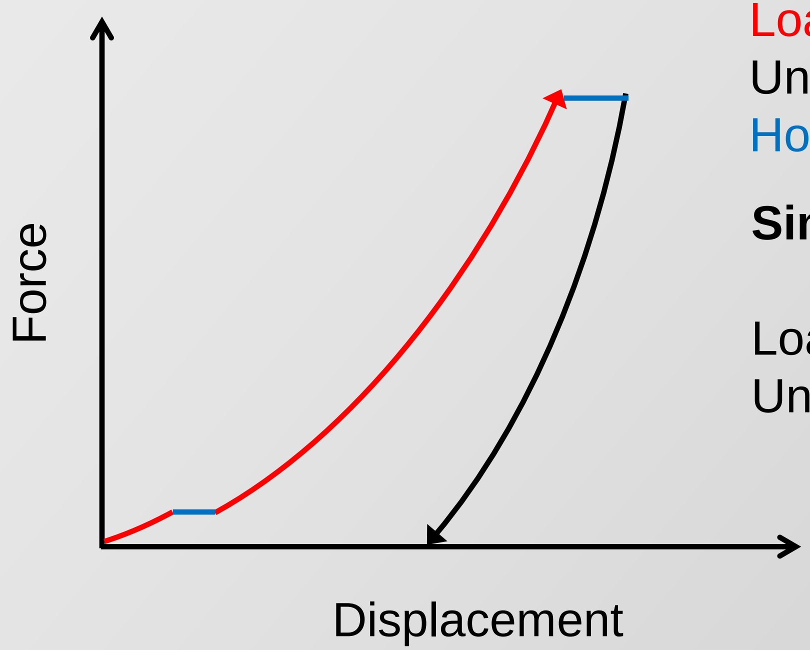
Loading
Unloading

Simple load-unload cycle

Load includes elastic and plastic responses
Unloading (assumed) only elastic recovery

Choose sharp indenter, e.g. Berkovich
The sharper the tip the earlier the transition from elastic to plastic deformation

Hardness & modulus test



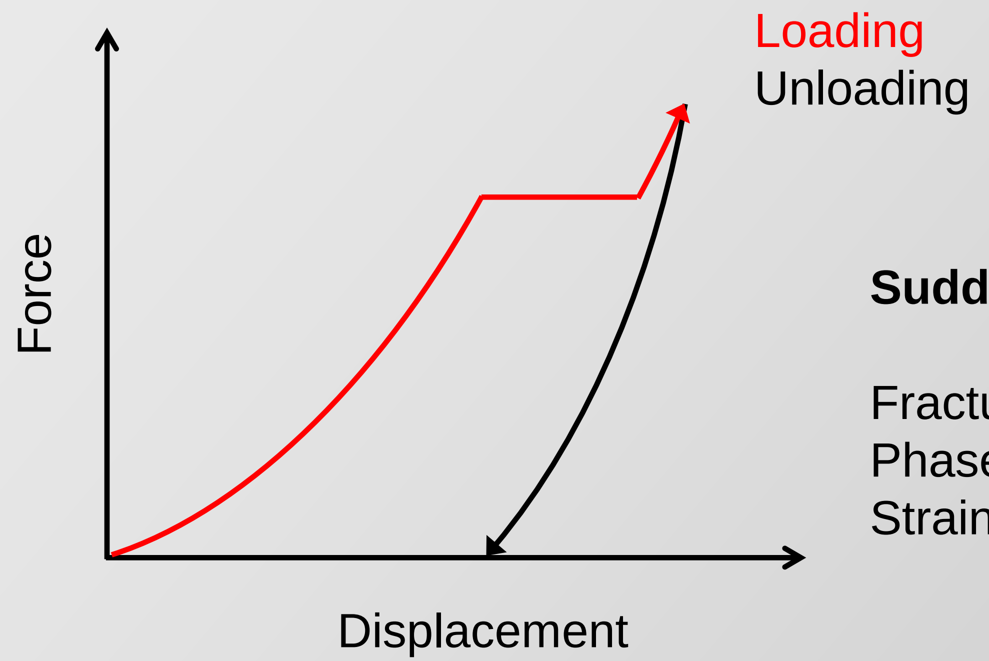
Loading
Unloading
Hold

Simple load-unload cycle

Load includes elastic and plastic responses
Unloading (assumed) only elastic recovery

Hold constant force to assess thermal drift or creep
Control load rate to assess strain rate sensitivity
Scrutinize elastic modulus value for signs of pile-up or sink-in
Indent to different depths for instrument response and size effects

Fracture tests

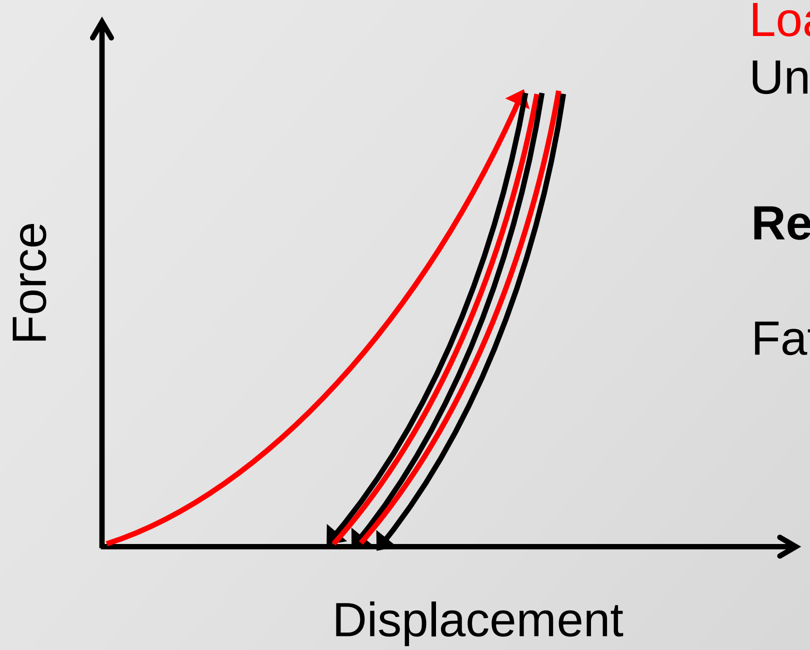


Sudden change in displacement

Fracture event
Phase transformation
Strain burst (staircase yielding)

Cracking event – choose sharp indenter
Crushing event – choose punch indenter
The type of event can be identified by looking at the elastic response
Many tests to get statistical population of data

Fatigue tests



Loading
Unloading

Repeated loading cycle

Fatigue behaviour (low cycle)

Fully unloaded or partially unloaded
Sharp or spherical indenter
Stresses can be changing sign beneath the indenter

Elastic-plastic tests

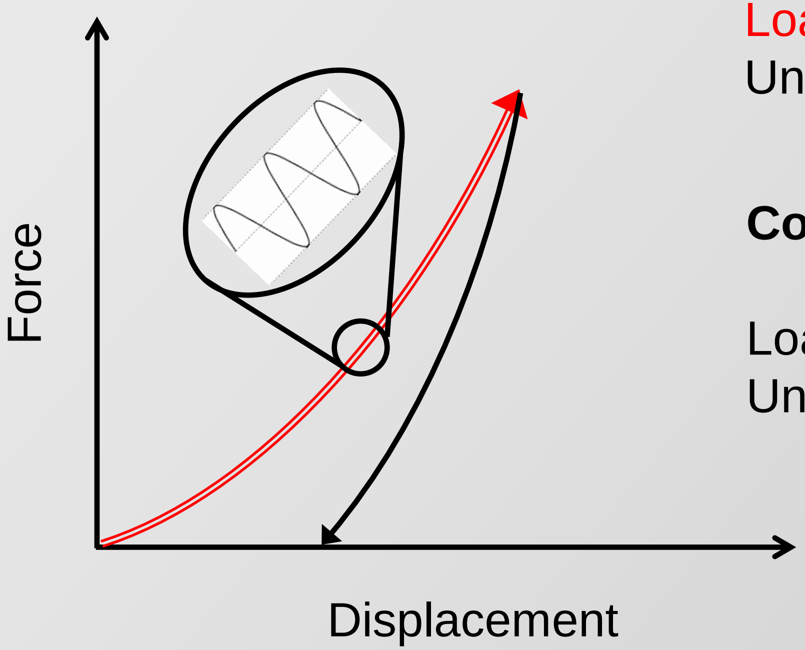
Loading
Unloading

Multi-cycle tests

Load includes elastic and plastic responses
Unloading (assumed) only elastic recovery

Partitioning between elastic and plastic response
Monitor elastic response throughout test
Generate indentation stress-strain curves (spherical indenters)
Onset of permanent deformation (yield and plastic flow)
or change in compliance associated with cracking

Sinus or oscillating tests



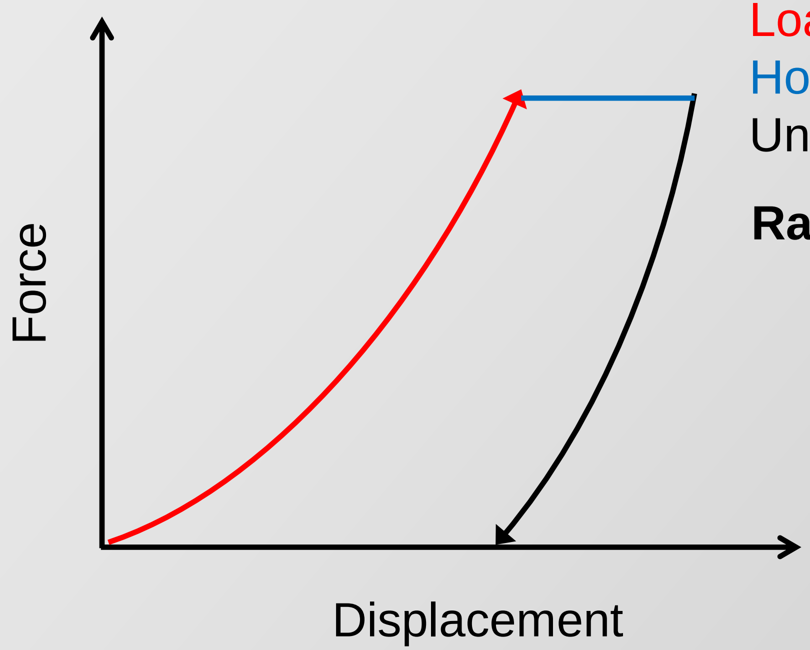
Loading
Unloading

Continuous contact stiffness cycle

Load includes elastic and plastic responses
Unloading (assumed) only elastic recovery

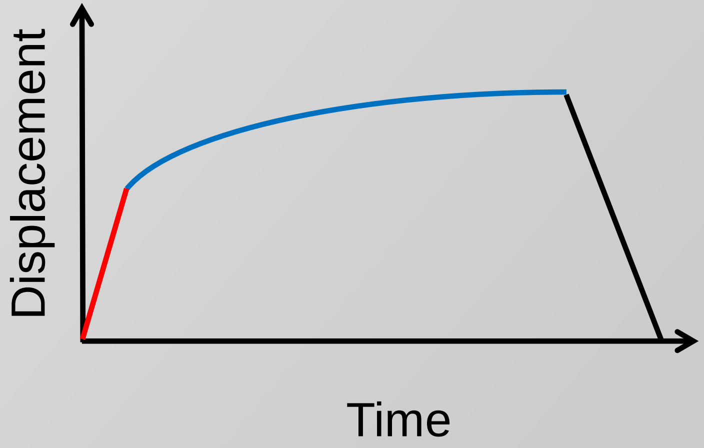
Small oscillation added to force control signal
Used to determine the contact stiffness as a function of load
Dynamic response during test

Time dependence tests



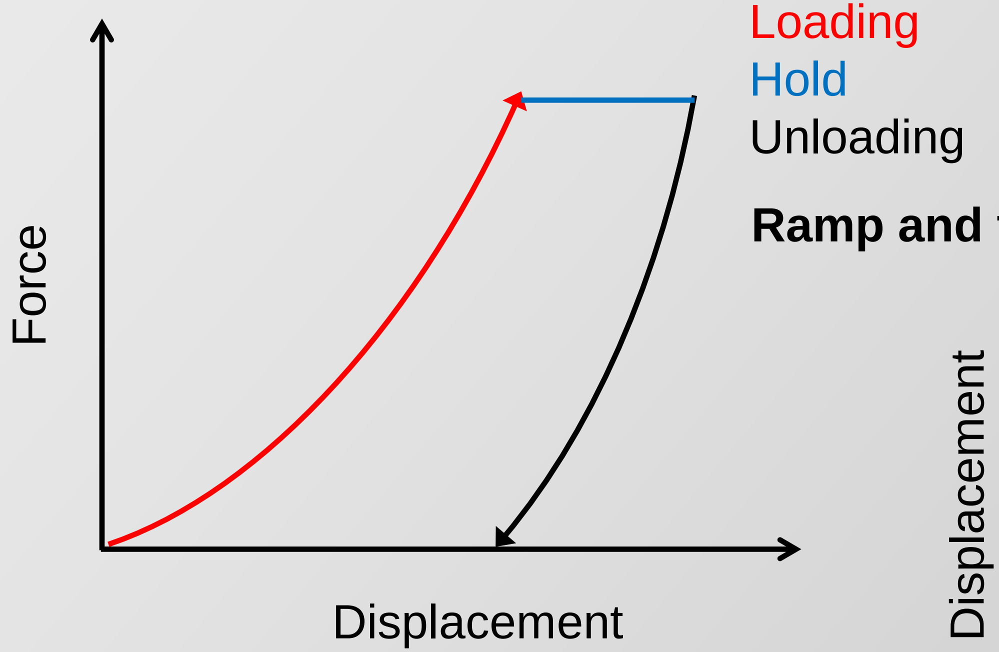
Loading
Hold
Unloading

Ramp and hold cycle

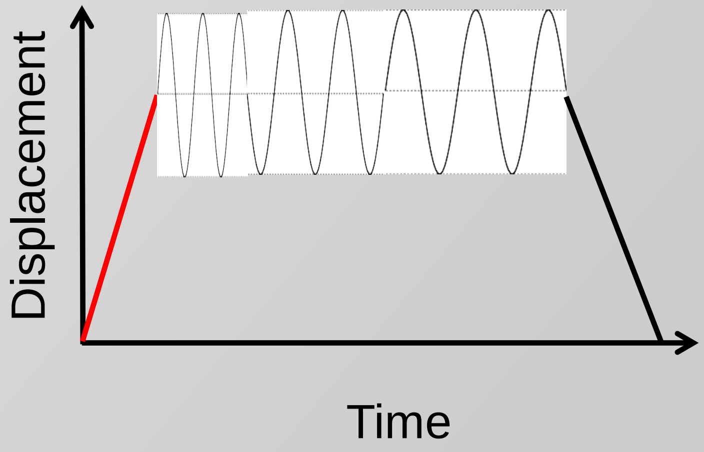


Choose punch indenter for viscoelasticity
Determine time dependent behaviour
Load rapidly at controlled rate
Hold constant force to assess time dependent response (creep)

Time dependence tests



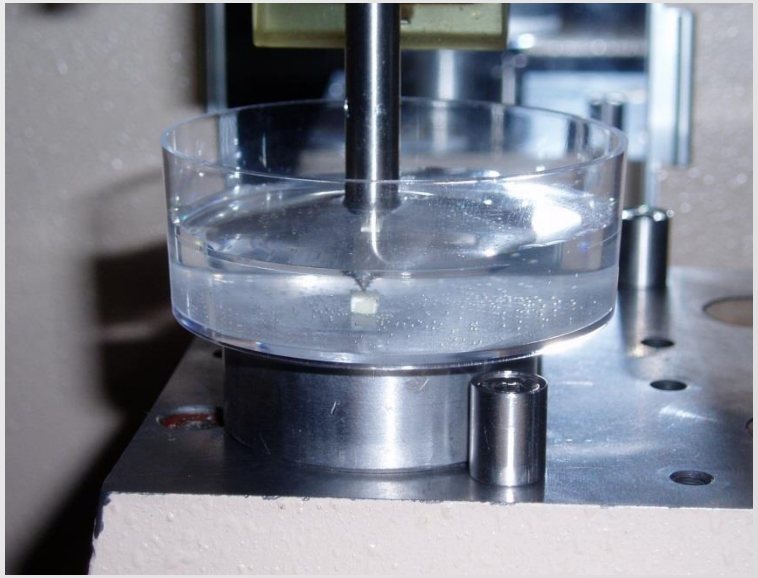
Ramp and frequency sweep



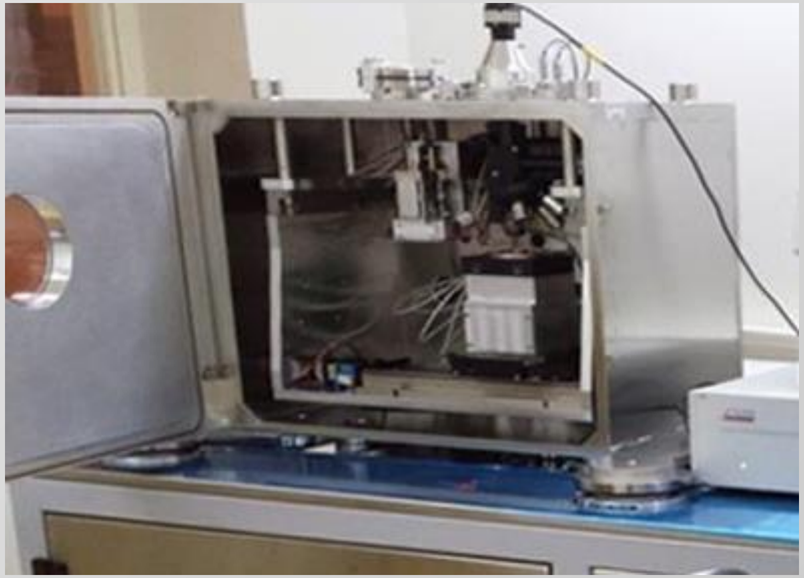
Choose punch indenter for viscoelasticity
Determine time dependent behaviour
Load rapidly at controlled rate
Oscillate force to assess frequency dependent response

Environmental tests

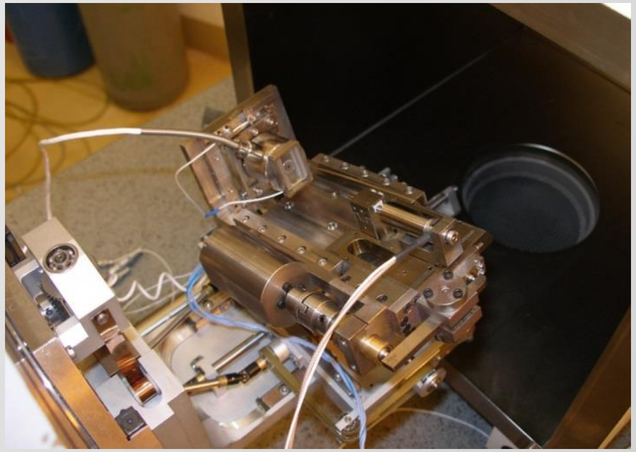
Liquid environments

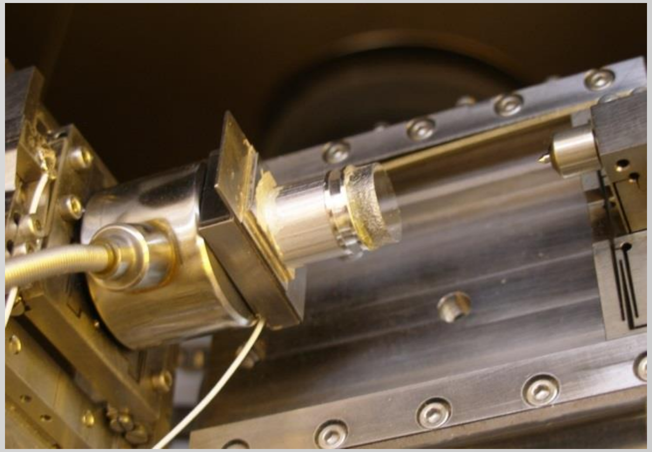


High temperature



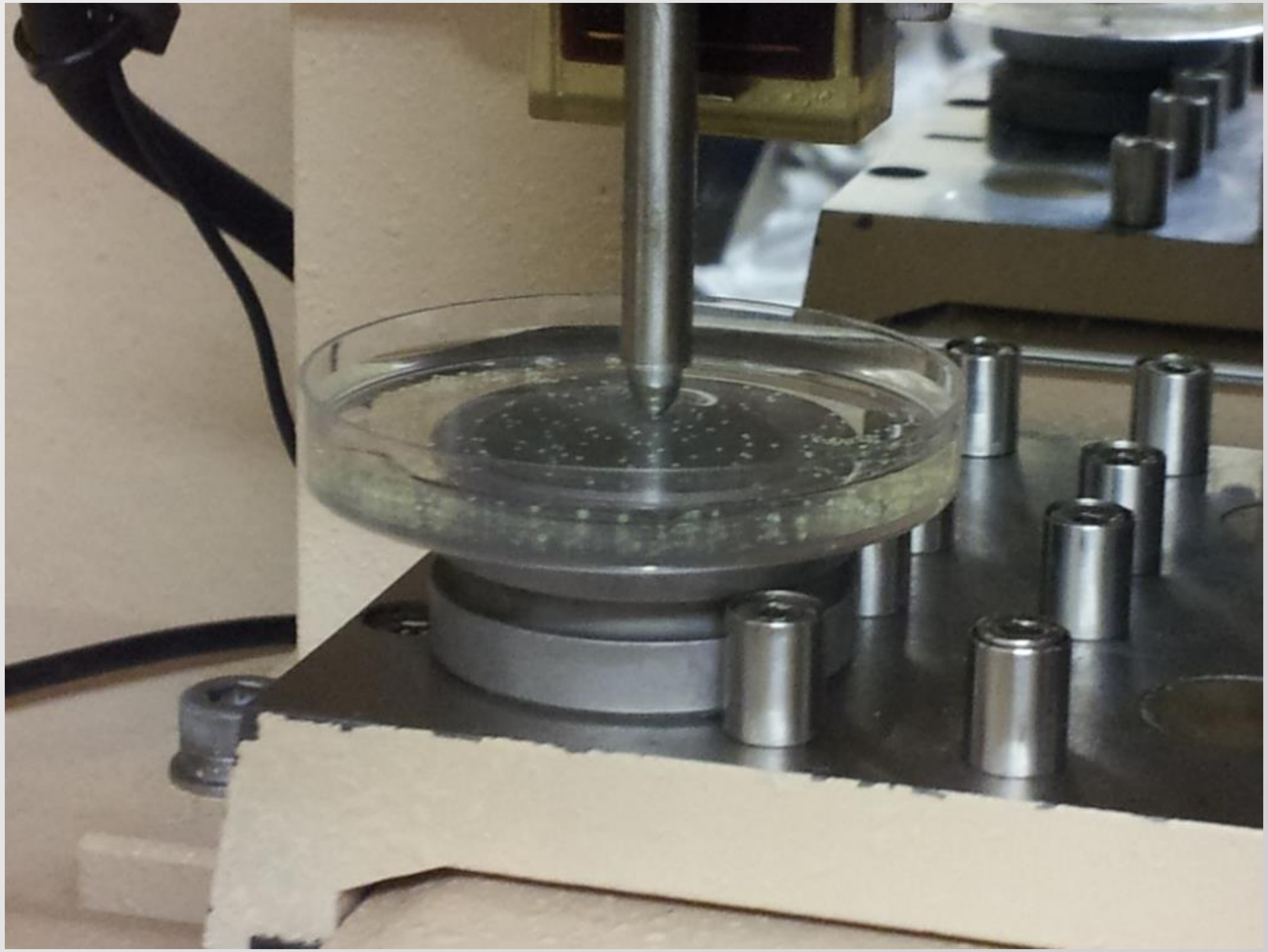
In situ
in the
SEM

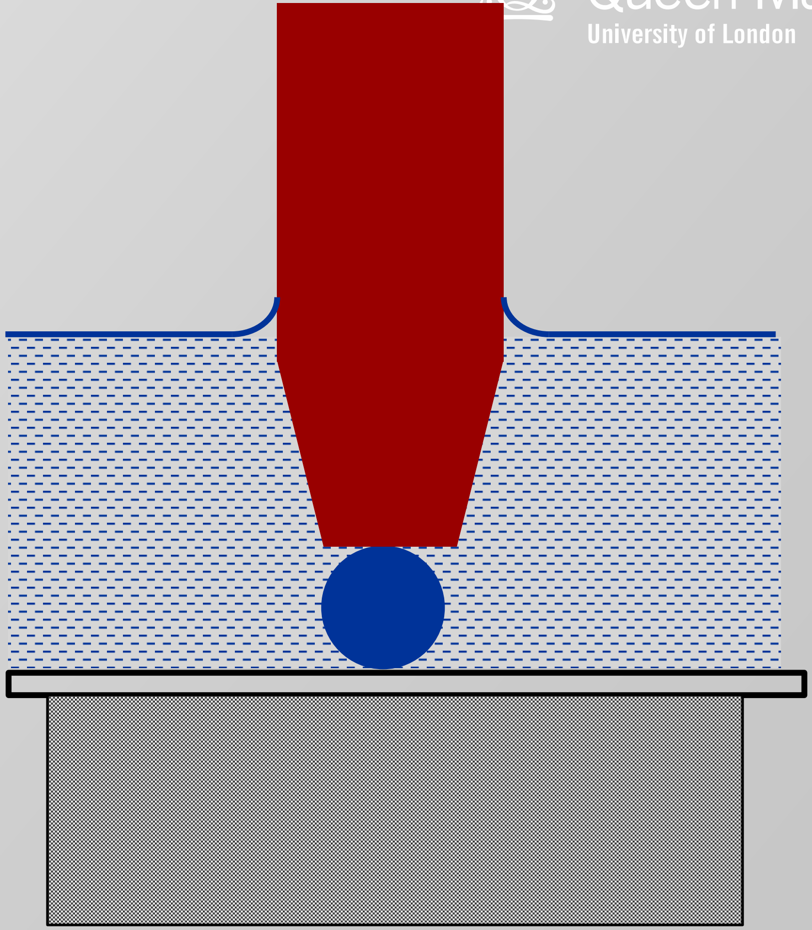




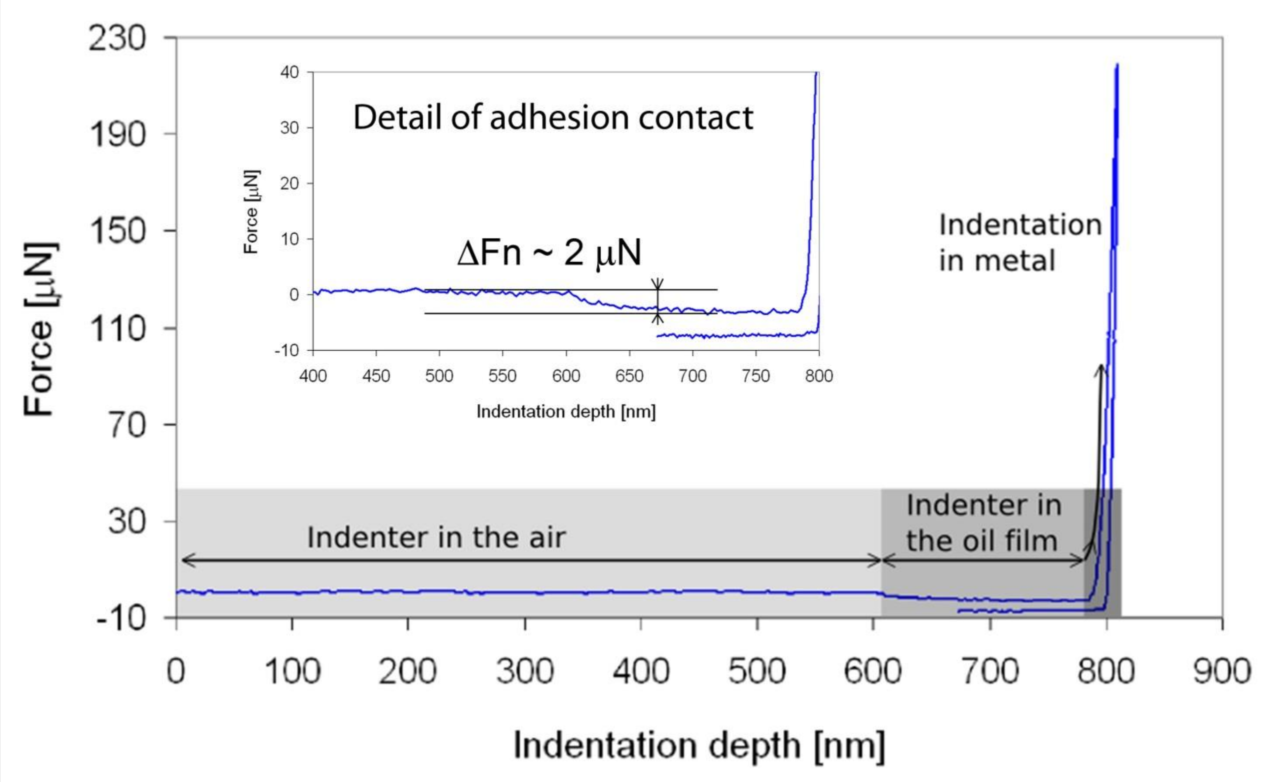
Environmental tests

Liquid environments





Nanoindentation through oil films



Oil smeared on steel

Stable ***Fn*** during approach

Surface tension (meniscus) phenomena:

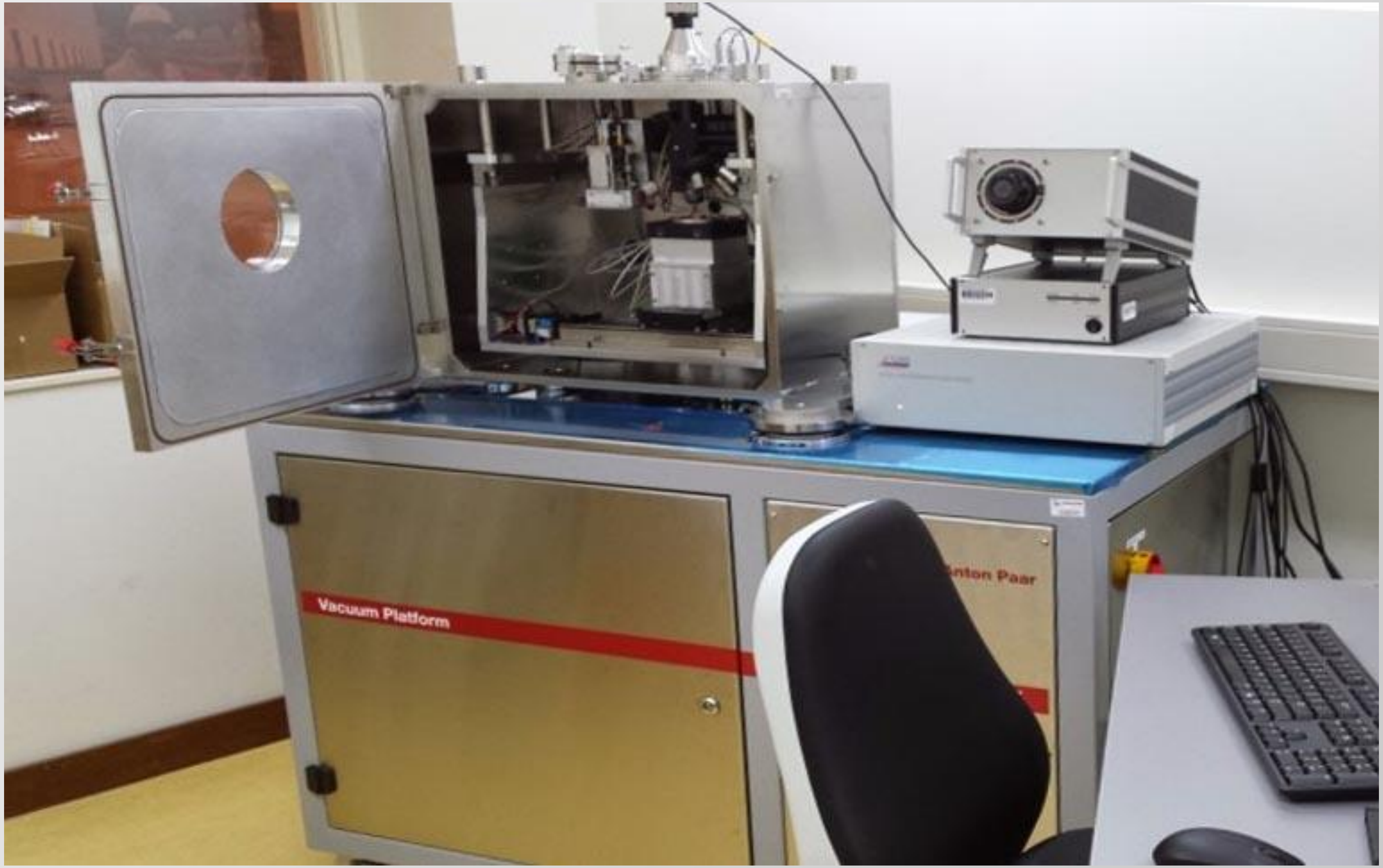
Fn drop ~ 2 μN

Thickness estimated at 180 nm

UNHT³ HT Standard Configuration

alemnis

Queen Mary
University of London



Summary

- **Many different ways a load cycle can be configured**

  Depending on the properties of interest in the material

  elasticity
  plasticity
  time-dependence
  frequency dependence
  fracture

- **Environmental testing**

  liquids
  temperature
  vacuum *in situ* in the SEM or TEM