EuCARD²
Workshop on Applications of Thermal Management Materials
6 November 2015

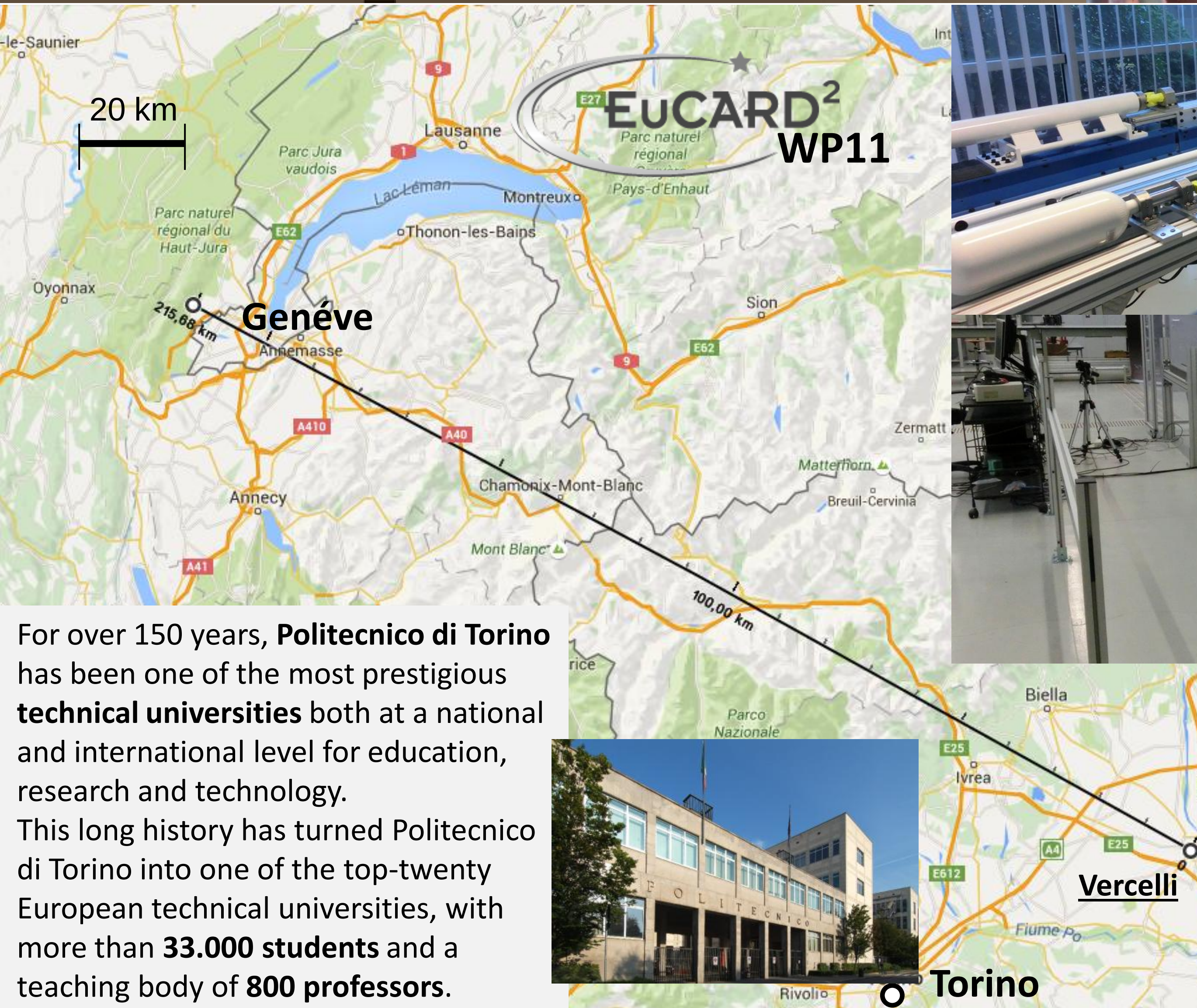
Mechanical Characterisation of Advanced Materials in Extreme Loading Conditions

L. Peroni

POLITECNICO DI TORINO

Mechanical and Aerospace Engineering Department

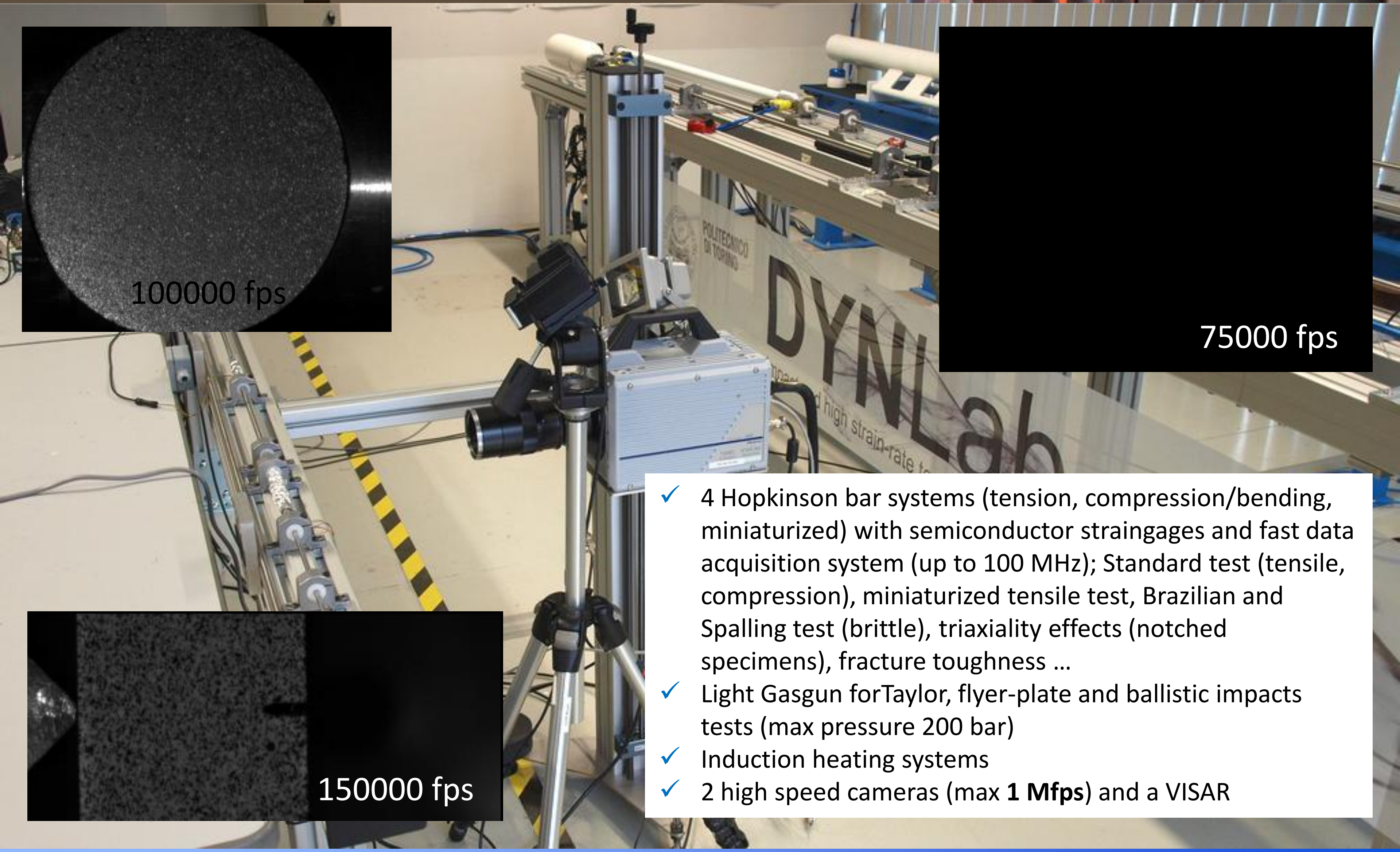
POLITECNICO DI TORINO
DIMEAS



For over 150 years, **Politecnico di Torino** has been one of the most prestigious **technical universities** both at a national and international level for education, research and technology.
This long history has turned Politecnico di Torino into one of the top-twenty European technical universities, with more than **33.000 students** and a teaching body of **800 professors**.

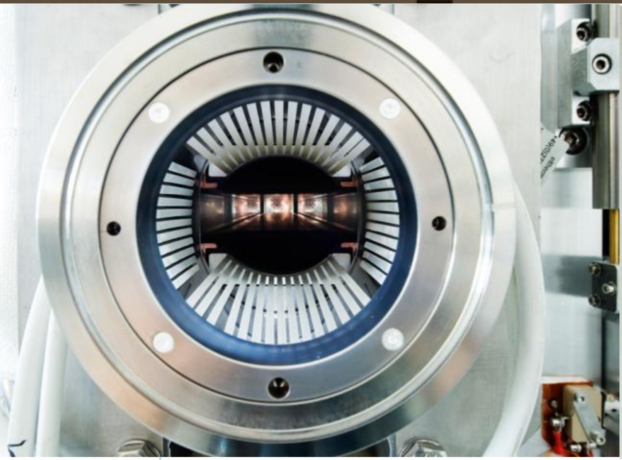
DYNLab is an integrated experimental and numerical laboratory operating in the field of **materials and structures behaviour under extreme loading conditions**. Impact and high strain-rate scenarios are investigated with dedicated experimental facilities and numerically simulated with non-linear finite elements codes.

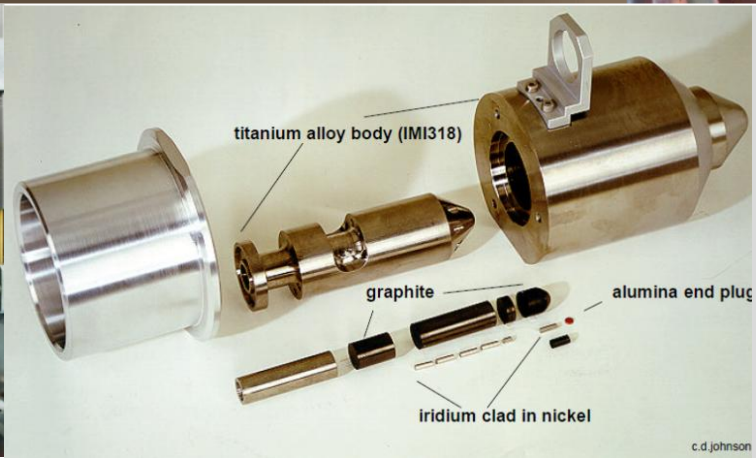
Politecnico di Torino - DYNLab



- ✓ 4 Hopkinson bar systems (tension, compression/bending, miniaturized) with semiconductor straingages and fast data acquisition system (up to 100 MHz); Standard test (tensile, compression), miniaturized tensile test, Brazilian and Spalling test (brittle), triaxiality effects (notched specimens), fracture toughness …
- ✓ Light Gasgun forTaylor, flyer-plate and ballistic impacts tests (max pressure 200 bar)
- ✓ Induction heating systems
- ✓ 2 high speed cameras (max **1 Mfps**) and a VISAR

Equipments for high strain-rate tests



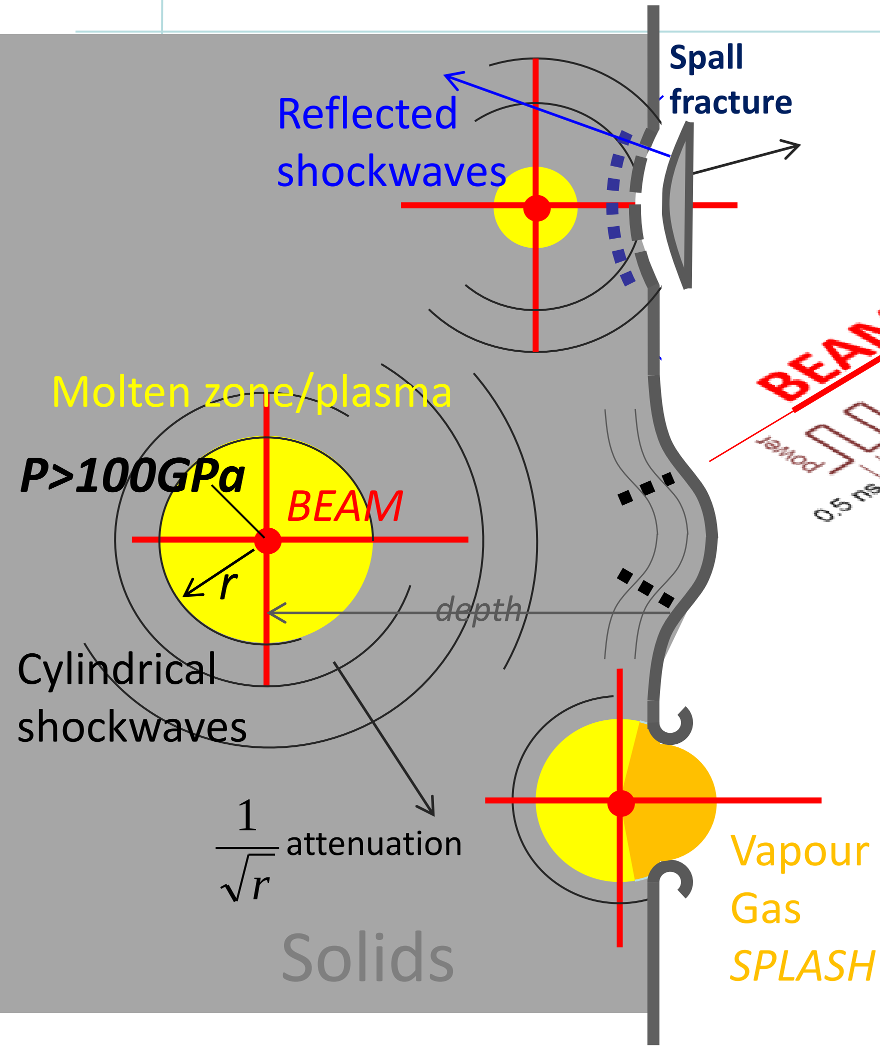


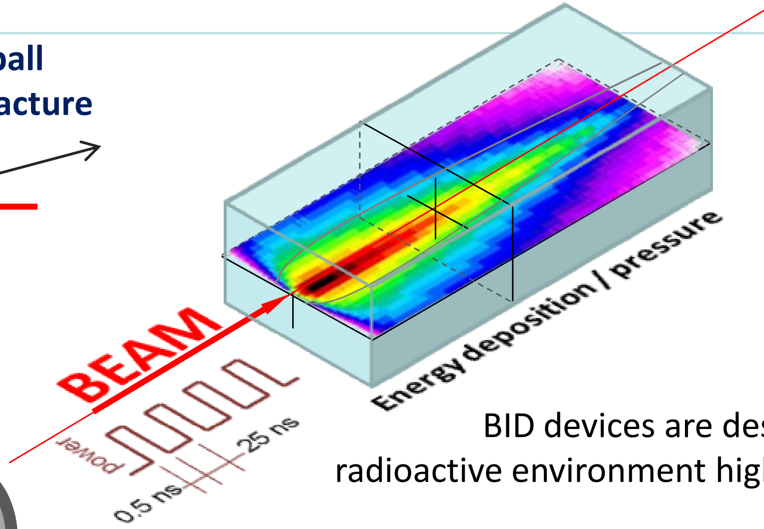
There are a lot of engineering scenarios in which the material can operate in high strain-rate and high temperature conditions such as metalworking, metal forming, aerospace and aeronautics structures, nuclear technologies, blasts, space debris impacts and high energy deposition (lasers and particle beams).

The materials involved in such phenomena have to satisfy a lot of requirements related to the mechanical response under the above mentioned loading conditions. The most important are high strength, good ductility and toughness also at high strain-rate and high resistance to creep and high temperature. For some applications also the resistance to corrosion, harsh and radioactive environments plays a key role.

This mixture of requirements makes ceramic-based and refractory materials the best candidates.

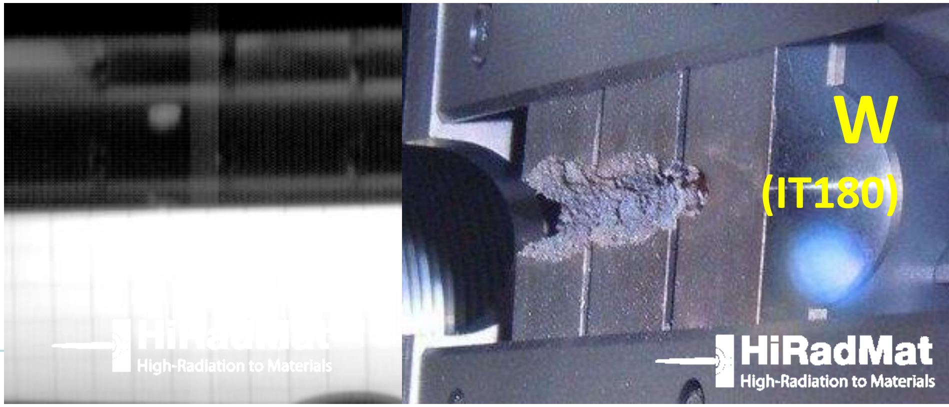
Advanced materials





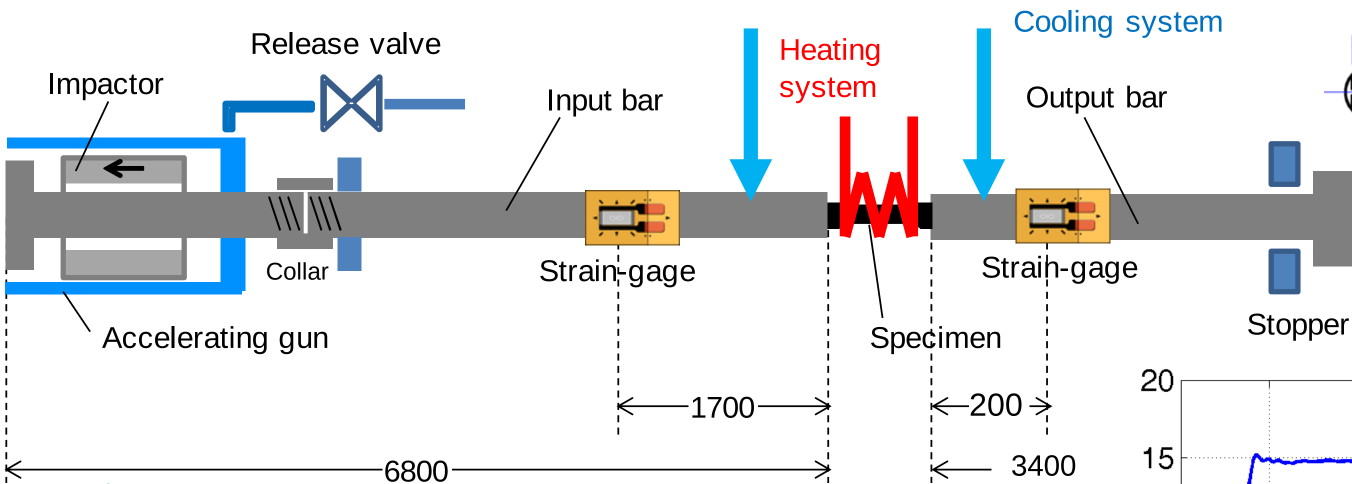
BID devices are designed to operate in harsh radioactive environment highly solicited from thermo-structural point of view.

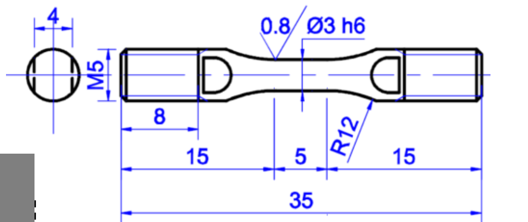
This context gives impulse to the development and testing of refractory metals and alloys based on <u>molybdenum</u>, <u>tungsten</u>, <u>rhenium</u> and <u>iridium</u>.



Courtesy of EN-MME Group CERN

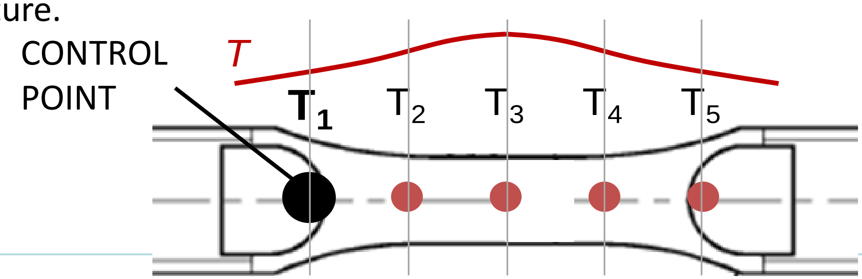
Material behaviour in Beam Intercepting Devices

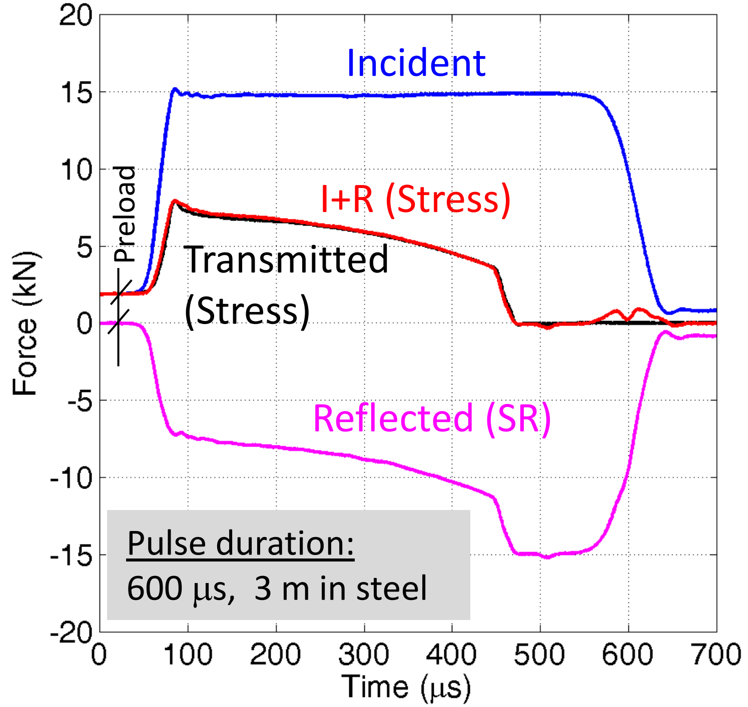




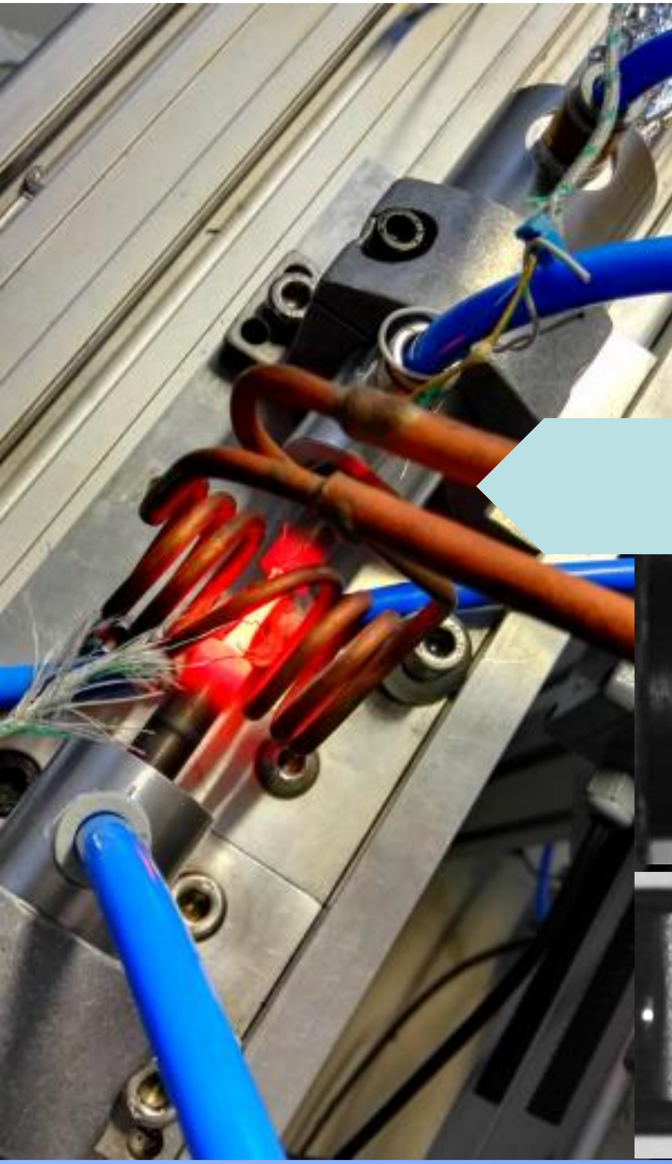
Direct tension Hopkinson Bar

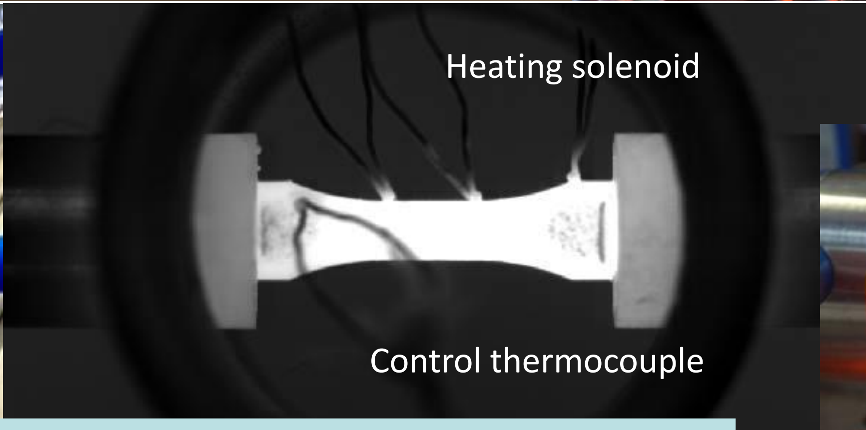
The heating of the specimens is obtained with an induction coil system, designed to concentrate the heat flux in the gage length of the specimen. A feedback loop, based on measurements from thermocouples directly welded on the specimen, is used to control the temperature.

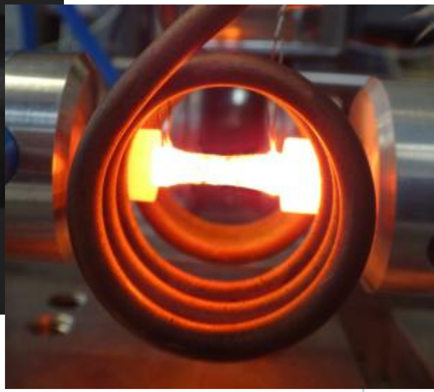




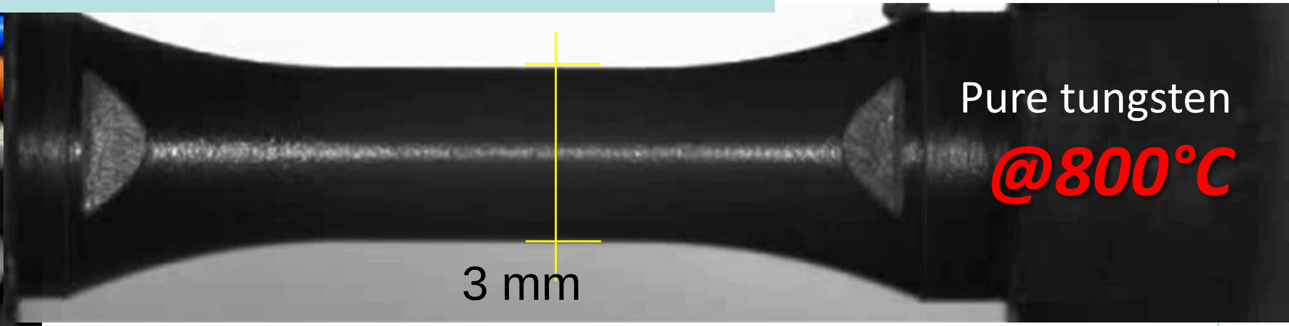
Experimental setup

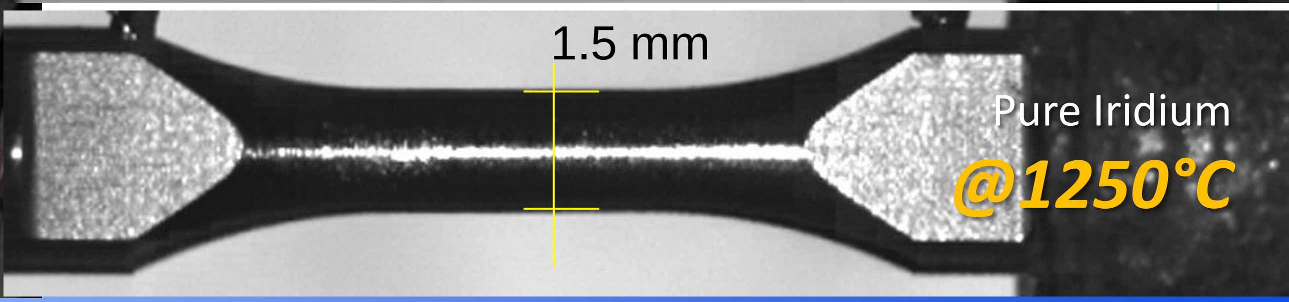




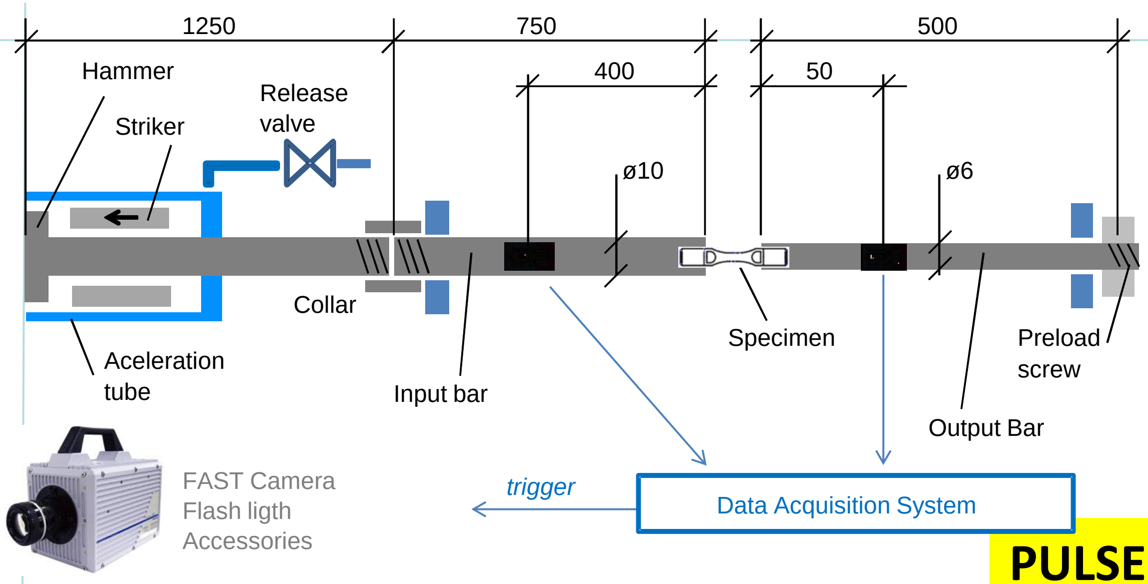


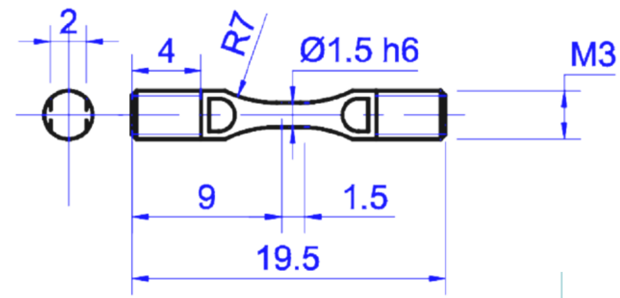
Res 512×128 px Fps 100000
Shutter 1/2713000 s





Atmosphere & Oxidation

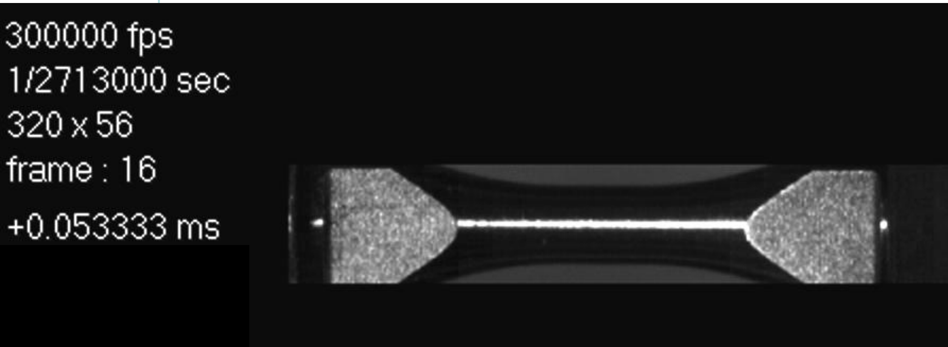




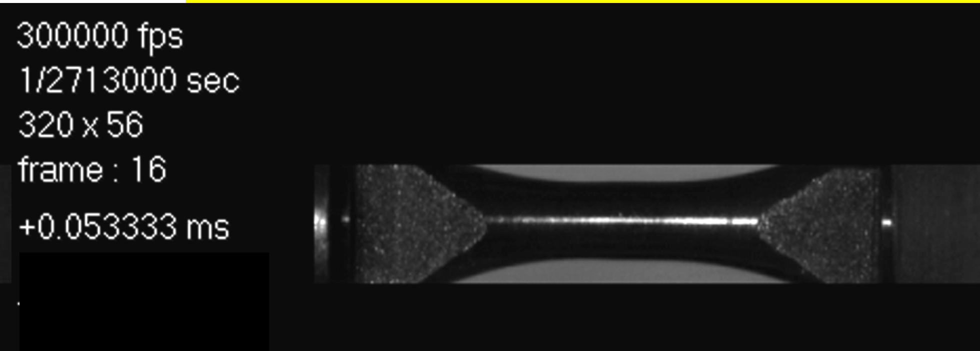
$$\dot{\varepsilon}_S = -\frac{2C_0}{L}\int_0^t \varepsilon_R(\mathrm{t})\mathrm{d}t$$

<u>PULSE DURATION: 100 µs</u>

about 25 m/s in 20 µs! (>10^5 g)



Iridium @500°C



Tungsten @400°C

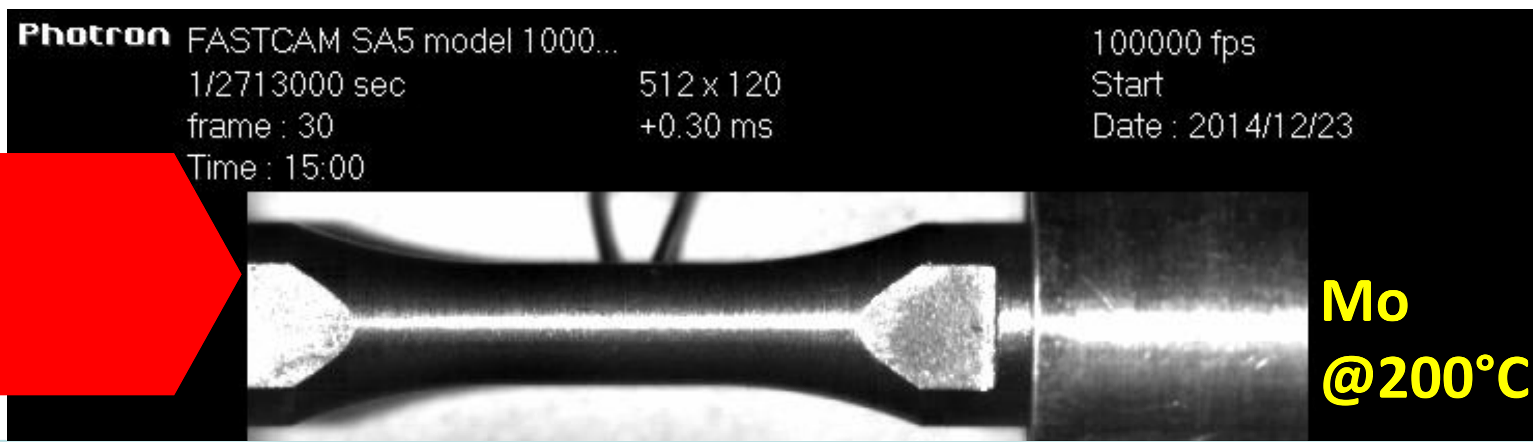
Miniaturized setup for ultra-high strainrate

Many refractory metals exhibit a brittle behaviour at high strain-rates at room temperature: tests on SHTB in these loading conditions were almost impossible to perform (many fractures in the threaded ends of the specimen)

IT180

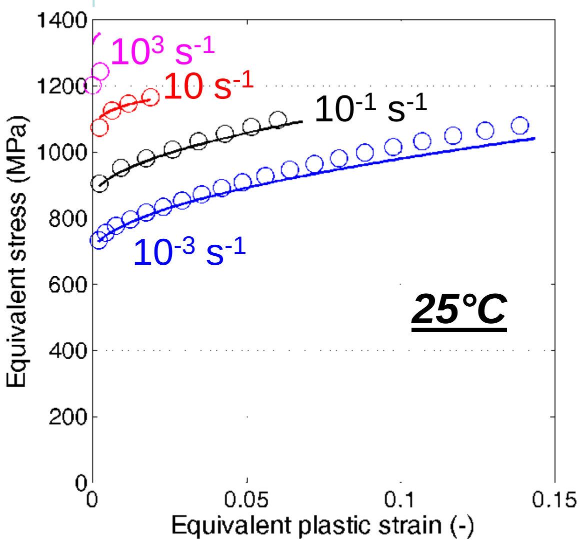
Mo

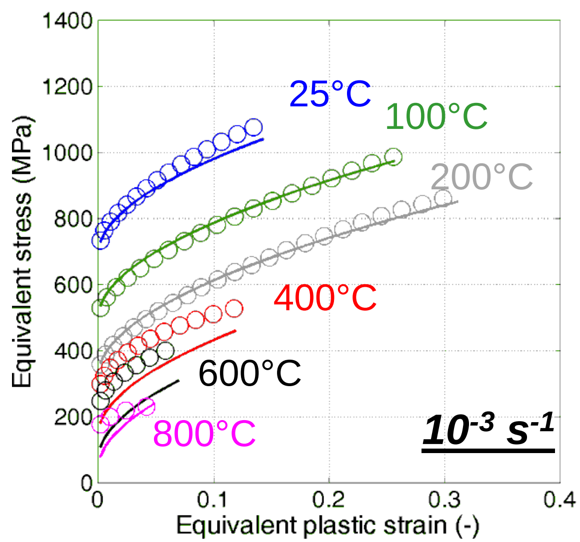
In few tests the fracture occurred in the specimen gage length, but due to the low elongation, the whole test occurs during the rise of the stress pulse with a low accuracy level in the data analysis.

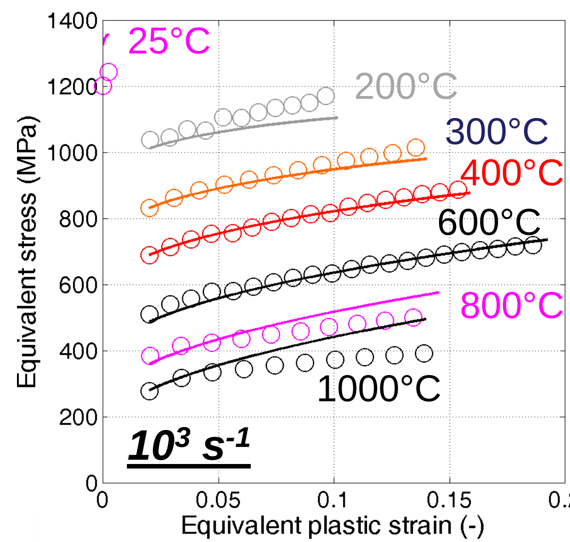


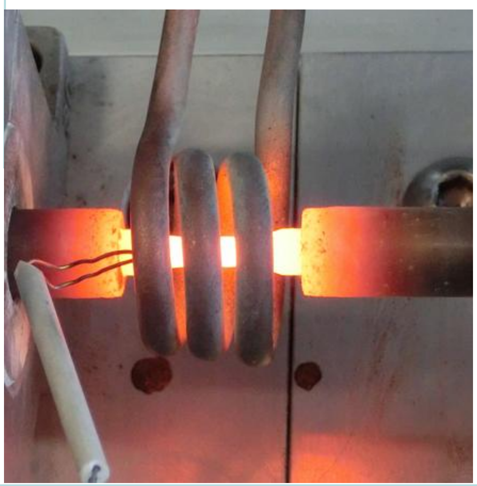
DBTT
IT180 >200°C
Mo>100°C
W>400°C

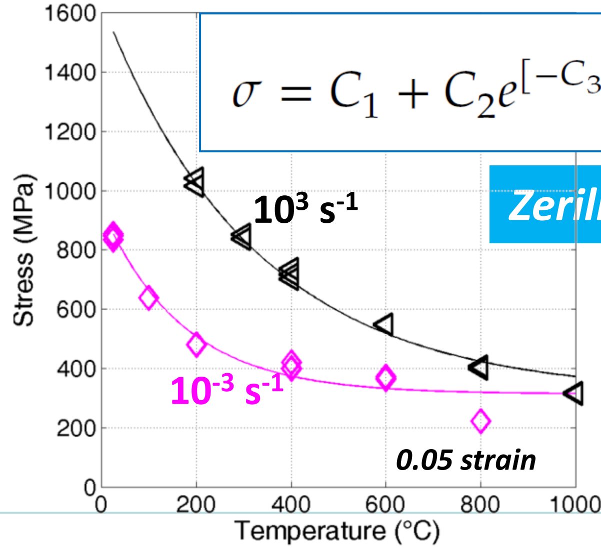
Ductile/Brittle transition











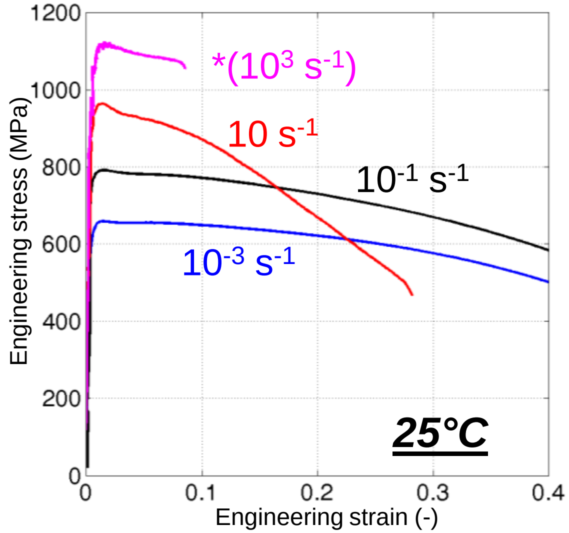
$$\sigma = C_1 + C_2 e^{[-C_3 + C_4 \ln(\dot{\varepsilon}^*)]T} + [C_5(\varepsilon^p)^n + C_6]$$

Zerilli-Armstrong strength model

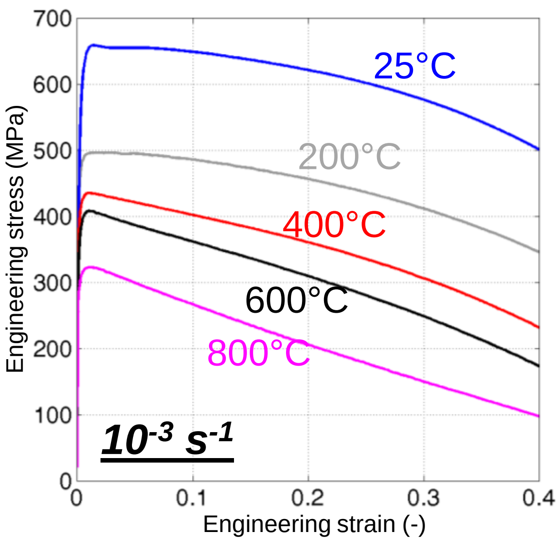
IT180

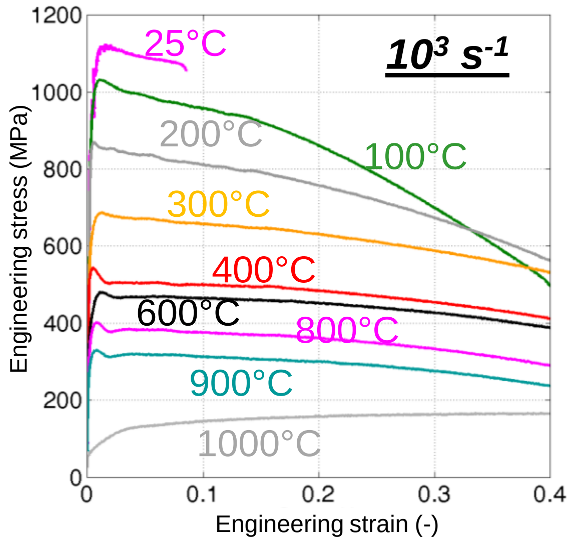
Courtesy of EN-MME Group CERN

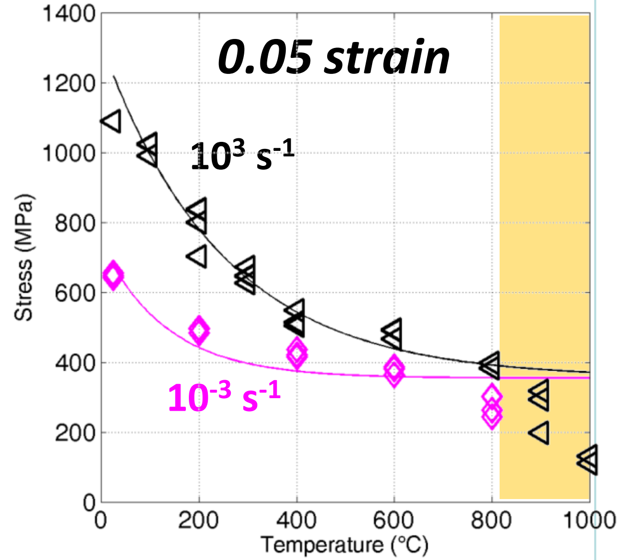
Result analysis: Inermet180



- Low strain at failure only @high strain-rate @RT
- Yielding instabilities
- Localized necking
- Transition over 900°C (recrystallization)
- Oxidation during heating

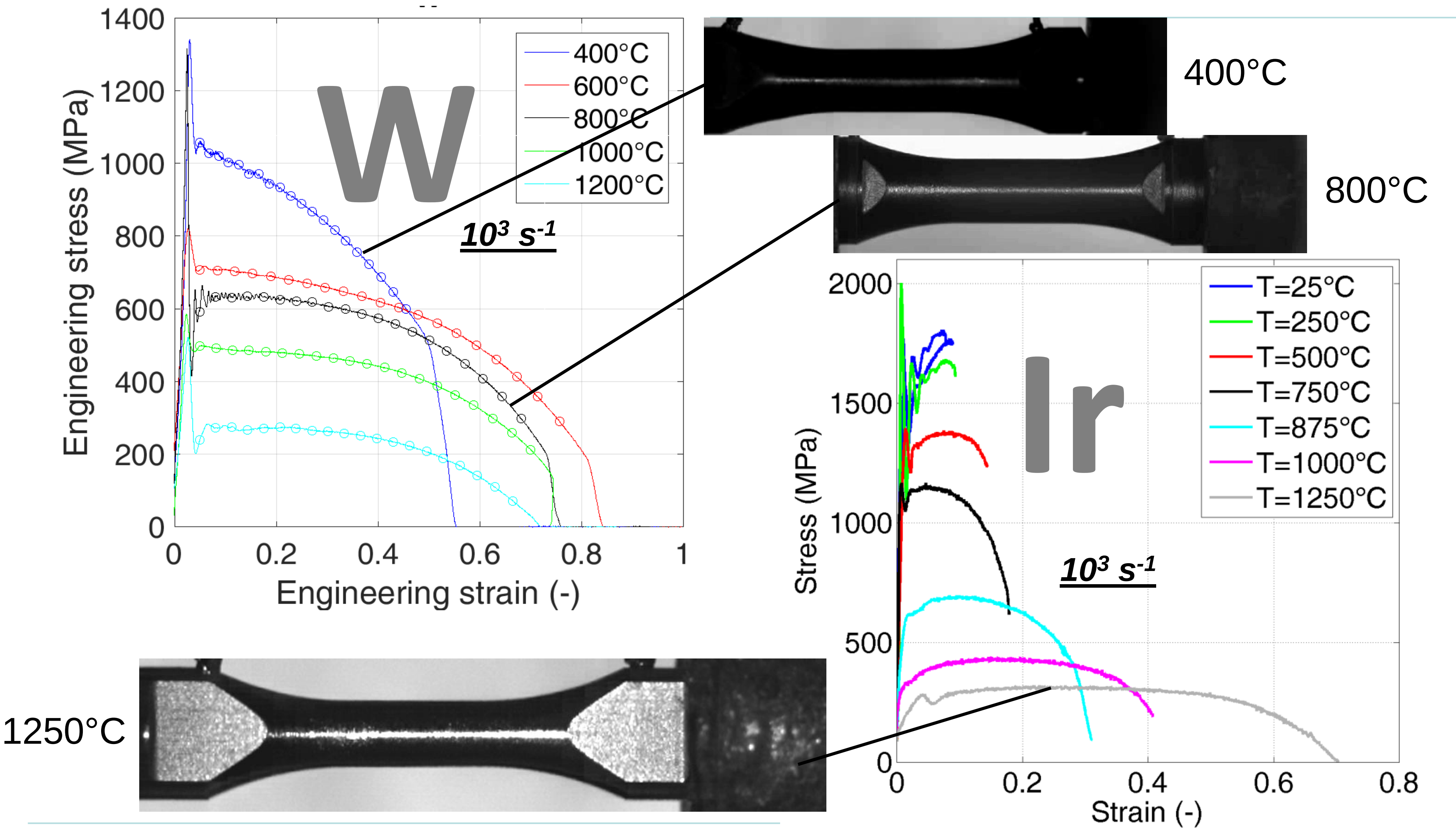






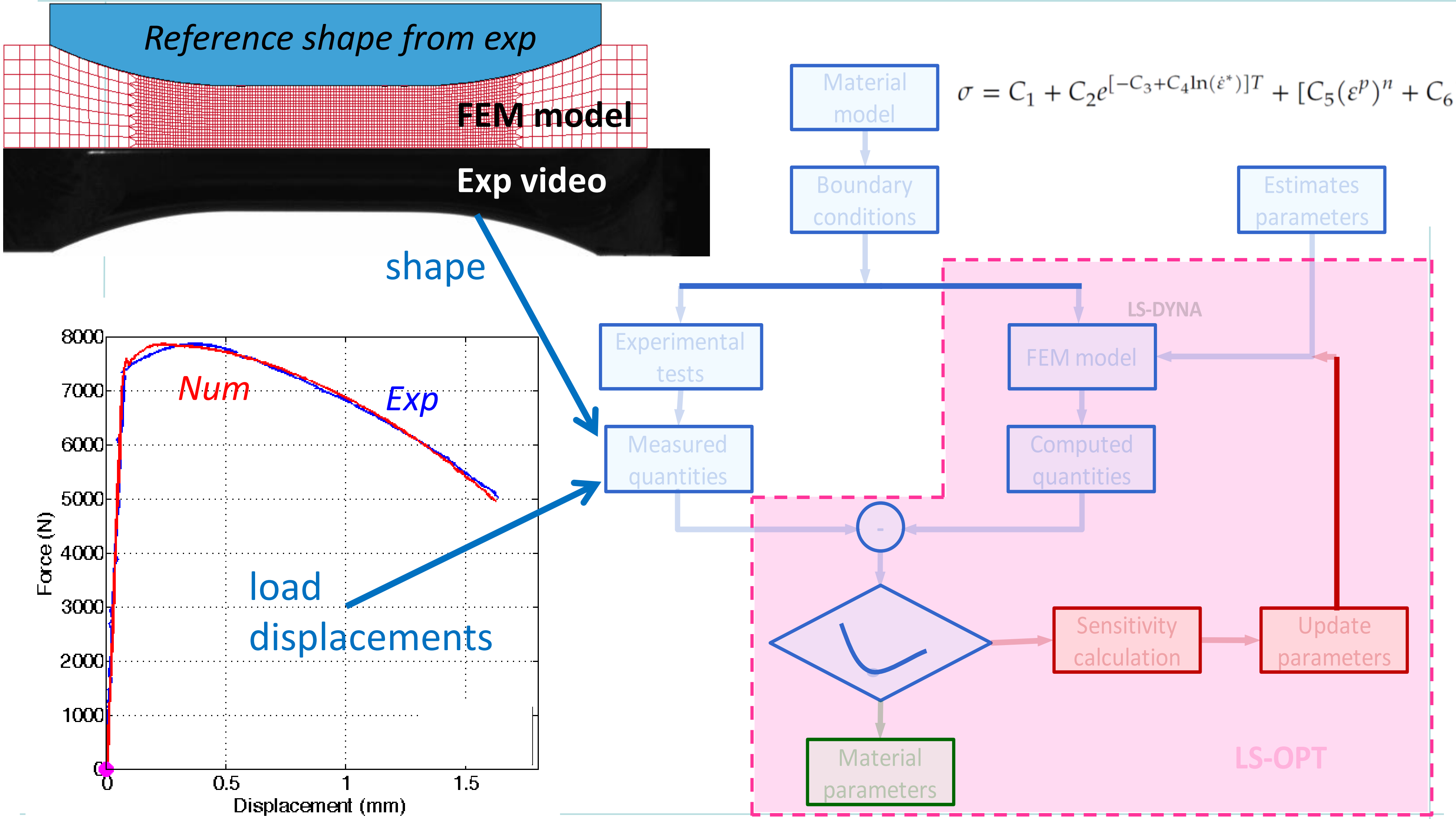
Courtesy of EN-MME Group CERN

Results – pure Molybdenum



Courtesy of EN-STI Group CERN

Results – Pure Tungsten , pure Iridium



$$\sigma = C_1 + C_2 e^{[-C_3 + C_4 \ln(\dot{\varepsilon}^*)]T} + [C_5(\varepsilon^p)^n + C_6]$$

Numerical analysis for model identification

- The investigation of the mechanical response of refractory sintered metals was performed, in last five years, at different temperatures and strain-rates.
- A methodology for testing materials at high strain-rate at various temperatures was presented. The methodology consists of performing dynamic tensile tests using a SHTB setup and heating the specimen using an induction coil system.
- The heating system is properly design to concentrate the heat flux in the gage length of the specimen: the investigated range in temperature was from room temperature up to 1250 °C (in the next future >1500°C).
- A recent improvement in the setup allows the fast video recording of the test at high temperature and strain-rates; a miniaturized setup was developed in order to reach strain-rates greater than 10^4 s^{-1}.
- The experimental data obtained from quasi-static and dynamic tensile tests are processed via a numerical inverse method based on FEM numerical simulations in order to perform the material model identification.

Conclusions & Future outlooks

Thank you for your attention

EuCARD²