High temperature creep study of recrystallized Tungsten: 3-point bending experiments and finite element simulation

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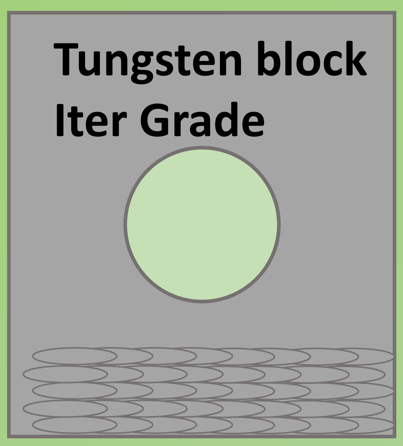
Introduction / Objectives

Tungsten is a candidate as plasma-facing material for fusion reactors. It will operate at high temperature, under irradiation and under high thermal stresses over long periods of time. These operating conditions will cause it to creep and possibly fail as a result[1]. Understanding its mechanical behavior under such conditions is therefore essential.

The ultimate aim of this study is to establish a constitutive law describing the creep behaviour of recrystallized Tungsten, based on a range of mechanical tests which include high temperature 3-point bending in association with FEM. We report here preliminary tests and results of simulations carried out using the Frederick-Armstrong law describing kinematic hardening.

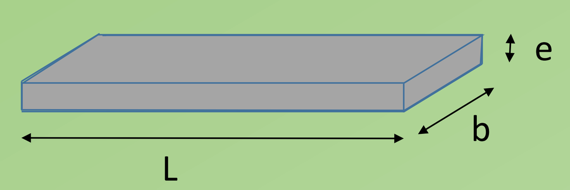
Materials



Made by rolling

- Elongated textured grains

Tungsten bending samples



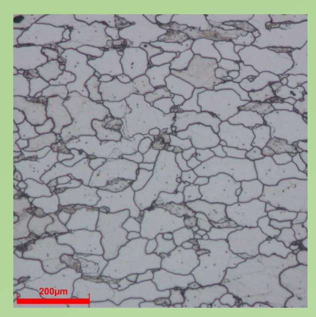
Dimension

L = 28 mm

b = 8mm

e = 1mm

Recrystallized Tungsten



Heat treatment

1700°C for 3h : batch A

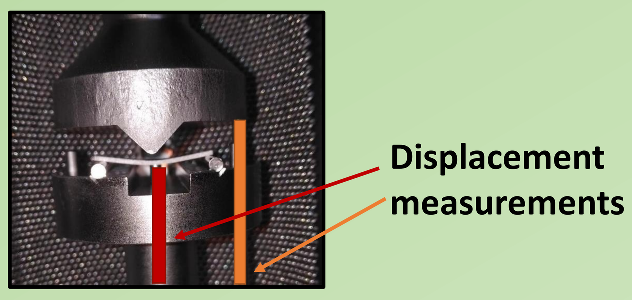
1700°C for 2h : batch B

Under Argon + 5% Hydrogen

Equipment

Three-point bending machine equipped with furnace

- Tungsten furnace can heat up to **1800°C**
- **Upper column** and **central point** displacement monitored with two LVDTs. Displacement measurements are **within a micron**.

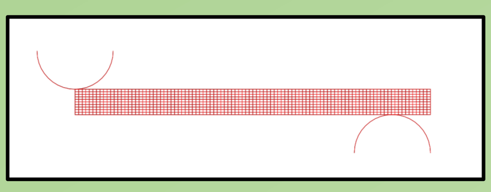


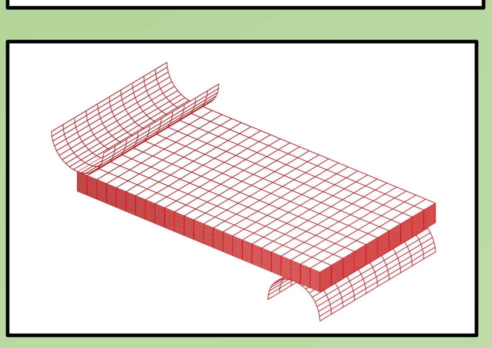
Equipment usually used on **ceramics.**

Many pieces of the device are made of **Tungsten** which spend many hours at high temperature.

Finite Element Simulation

2D and 3D FEM model





Frederick-Armstrong law[2] viscoplastic constitutive law with kinematic hardening describing primary creep

$$\dot{\varepsilon}_p = \left(\frac{\sigma - X}{K}\right)^n$$

$$\dot{X} = \frac{2}{3} C\dot{\varepsilon}_p - DX\dot{p}$$

licos@Cast3m[3] code used for the numerical calculations

Mfront[4] code used for the implementation of the constitutive law

Finite logarithmic strain approximation

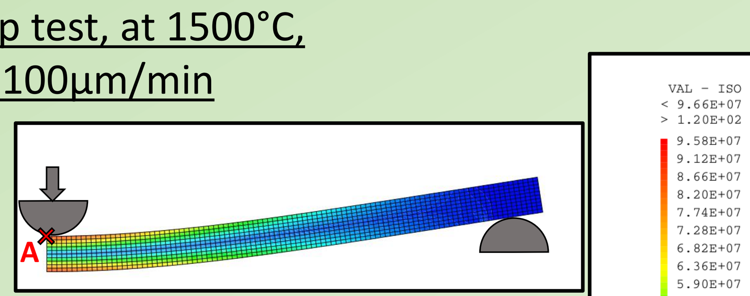
Simulation of a three-point bending creep test, at 1500°C, with a constant crosshead speed of 100µm/min

Longitudinal symmetry: only half beam is modelled

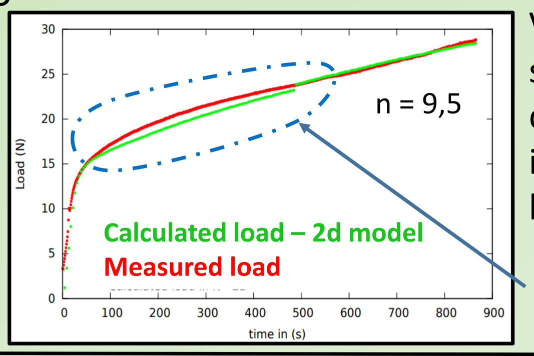
Upper and lower supports: **rigid body displacement**

Experimental upper support displacement is applied onto the beam (point A): the constitutive law is optimised with the numerical load curve

Adequate representation of material behaviour



Von Mises stress distribution in deformed beam



* cf. prospects

Results

Constant crosshead speed test:

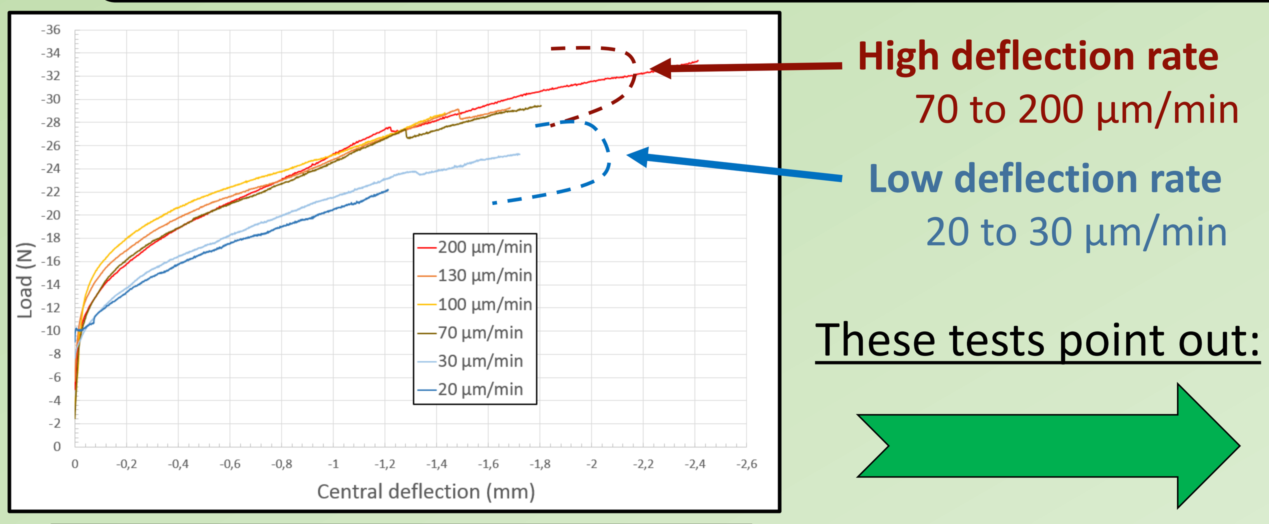
from **20 µm/min** ($\dot{\varepsilon} = 3{,}2.10^{-6}s^{-1}$)

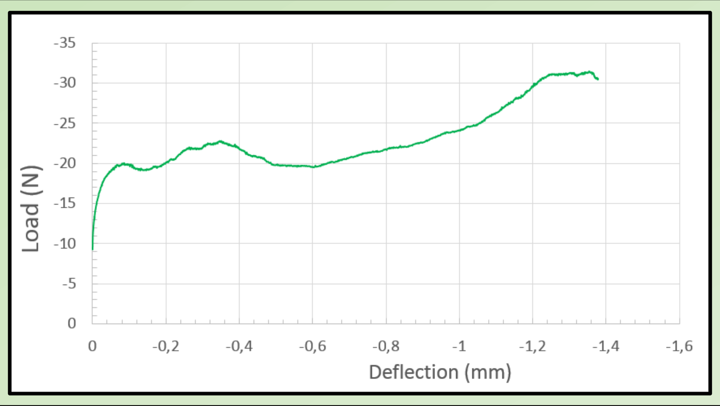
to **200 µm/min** ($\dot{\varepsilon} = 3{,}2.10^{-5}s^{-1}$)

Conditions

1500°C & flowing mixture of **Argon + 5% Hydrogen**

Except one test **accidentally** carried out under a **static atmosphere**



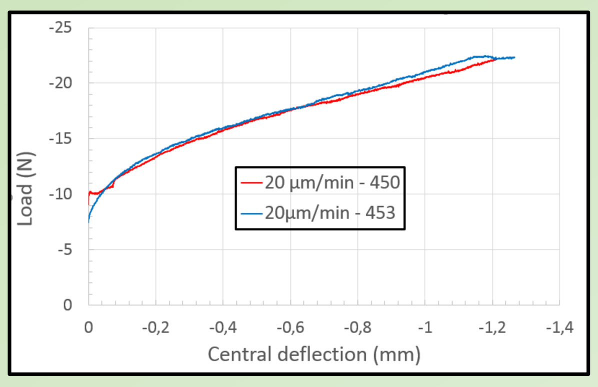


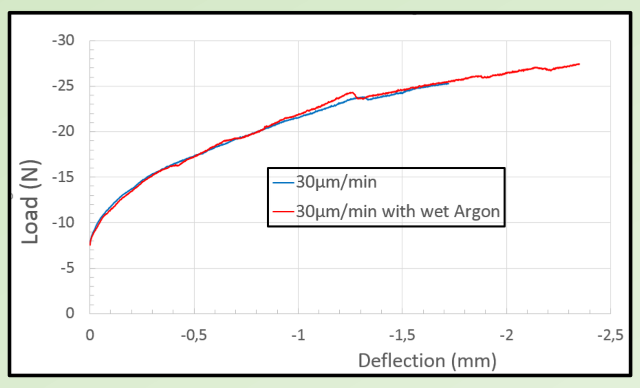
These tests point out:

- **Hardening** phenomenon (load increases with the deflection)
- Two domains : **low deflection rate** (20 to 30 µm/min) and **high deflection rate** (more than 70 µm/min)
- At high deflection rates at least, **small crosshead speed influence** upon material behaviour: similar flow stress for tests between 70 to 200 µm/min. However, **the steady-state creep is consistent** with the strain rate (i.e. σ increasing function of $\dot{\varepsilon}$)
- Some **inconsistencies during the primary creep**: load applied is lower at 200µm/min than at 100µm/min
- **Strong effect** of environment

Reproducibility of our tests ? Plastic or viscoplastic behaviour ? Atmosphere effect ?

A. Reproducibility



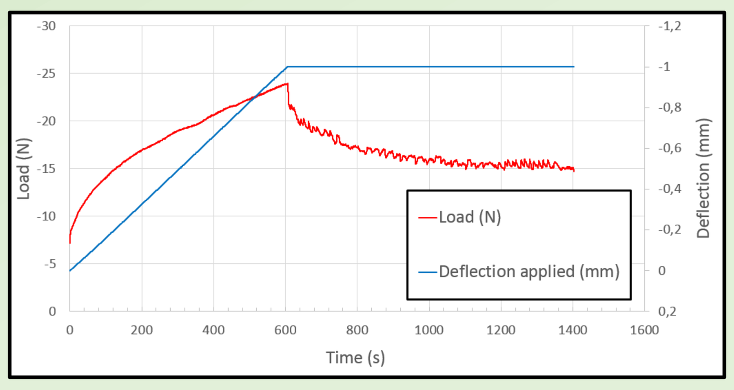


Several three-point bending tests with identical strain rate:

- **Left:** two samples from two batches (A & B) at 20 µm/min
- **Right:** two samples from same batch (B) at 30 µm/min

Consistent behaviour of our material

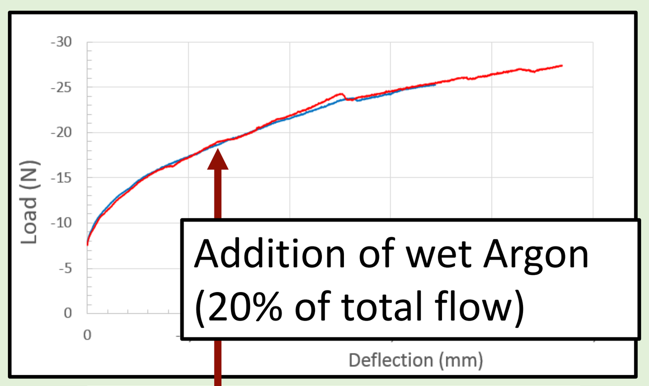
B. Relaxation test

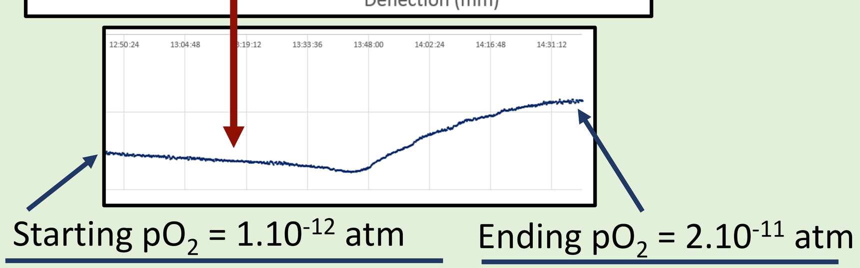


Load progressively decreases during relaxation stage

True viscoplastic behaviour

C. Atmosphere influence





Two similar creep tests:

- Imposed deflection rate of 30 µm/min
- At 1500°C

But:

- Sudden increase of the oxygen partial pressure during the second test

No particular effect on the behaviour

Conclusions / Prospects

- We carried out **multiple three-point bending creep** test on **recrystallized Tungsten** bars at **1500°C**.
- Tests are modelled using **Frederick-Armstrong behaviour law**
- Some questions remain before we can establish a proper constitutive law:

1. **Two distinct group** of tests were observed at low and high deflection rates.
2. **Inconsistencies in primary creep** of high deflection rates.

- We feel that these issues may only be resolved through characterisations of microstructure **(raw, after recrystallization and after deformation).**
- **Dynamic recrystallization effects**[5] (*) might explain the behaviour at early stages of the material

References

[1] Rieth et al., *Tungsten as a Structural Divertor Material.* Advances in Science and Technology, Vol. 73. 2010

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[3] Helfer et al. J. Nuc. Eng & Des. 294 (2015) http://www-cast3m.cea.fr

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[5] Poliak and Jonas. Acta mater. 1996.

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