Creep Characterization of Refractory Materials at High Temperatures Using the Integrated Digital Image Correlation Technique

Lucas Teixeira – University of Orléans

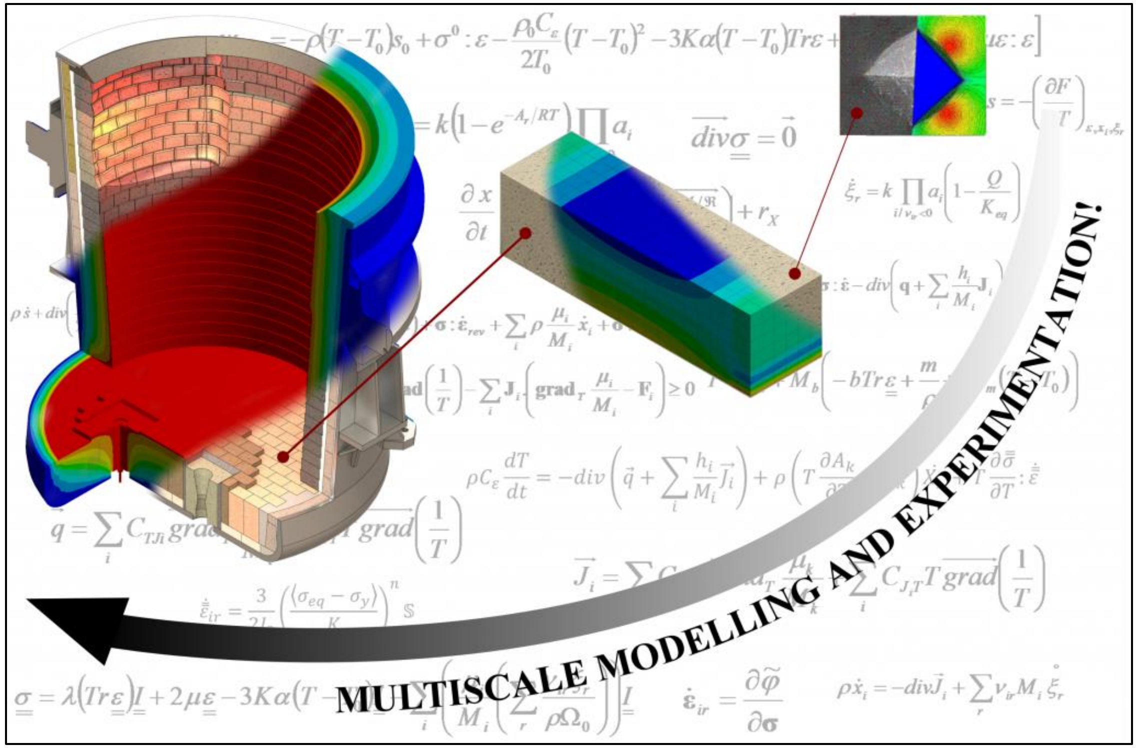
Jean Gillibert
Eric Blond
Thomas Sayet

lucas.breder-teixeira@univ-orleans.fr

ATHOR – Advanced THermomechanical multiscale mOdelling of Refractory materials

Partners

- Université de Limoges
- alteo
- Université d'Orléans
- IMERYS
- AGH
- RHI Magnesita
- RWTH Aachen University
- Pyrotek
- Montan Universität (www.unileoben.ac.at)
- Saint-Gobain
- Universidade do Minho
- Tata Steel
- Universidade de Coimbra
- Safran
- FIRE



www.etn-athor.eu

15 Early Stage Researchers (ESRs)

Context – Refractories and the Steel Ladle

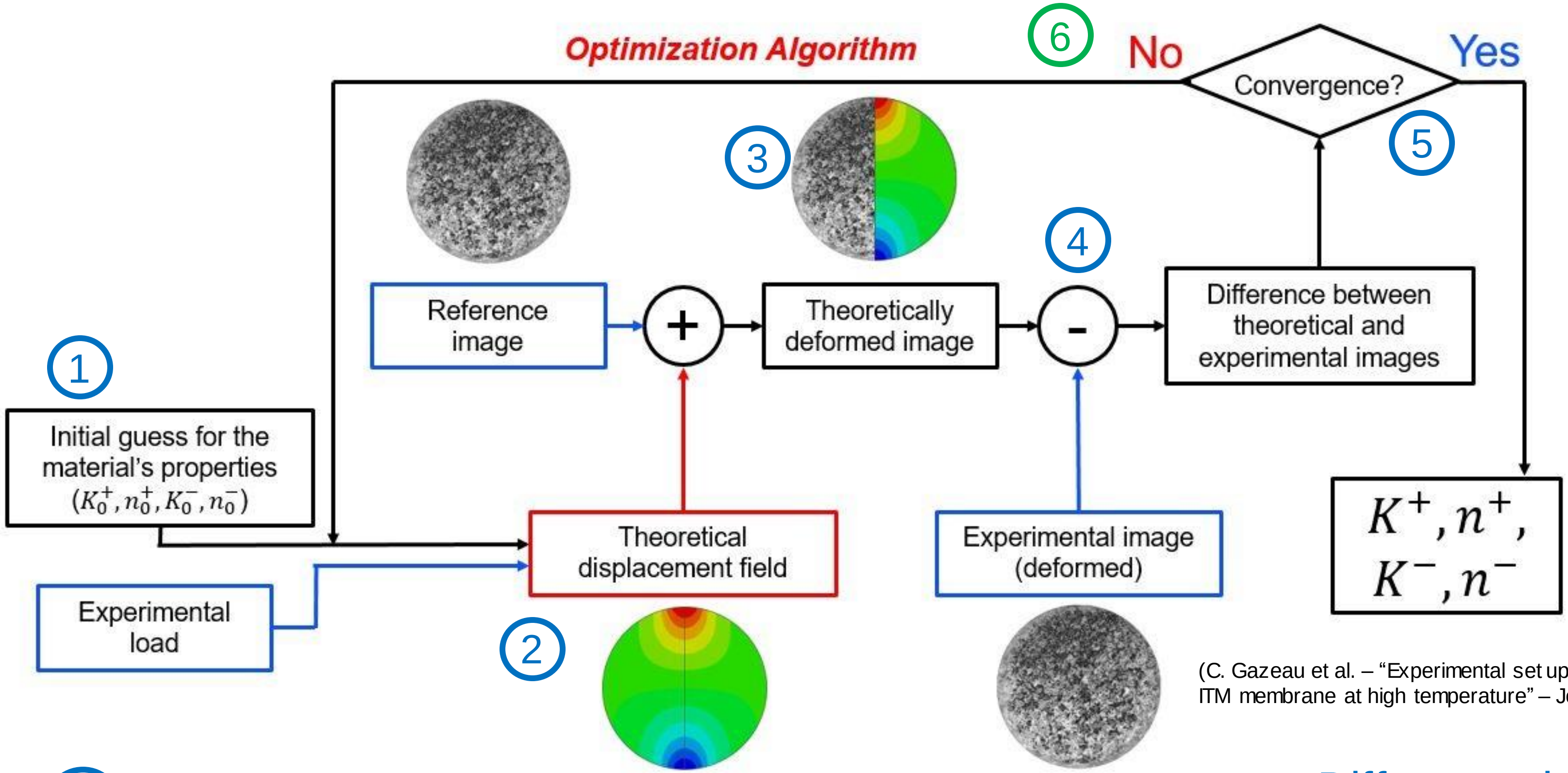
To predict the suitability of a refractory lining to a given production process, it's necessary to know its **mechanical behavior**.

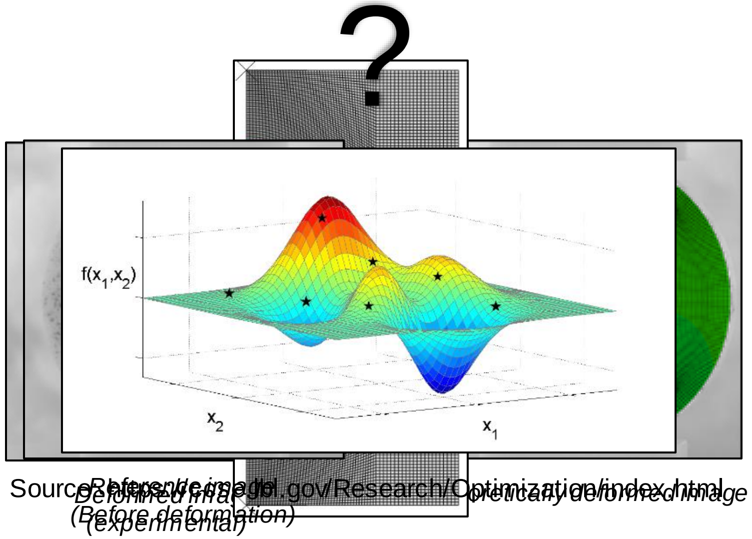
In general, refractories at high temperatures present a **viscoplastic damageable** behavior.

The **characterization and modeling** of refractory linings is still a scientific challenge.

The aim of this work is to propose a **characterization setup** based on the **I-DIC** technique and **Brazilian tests** for the identification of **asymmetric creep constitutive models** parameters

I-DIC technique – Full field measurements



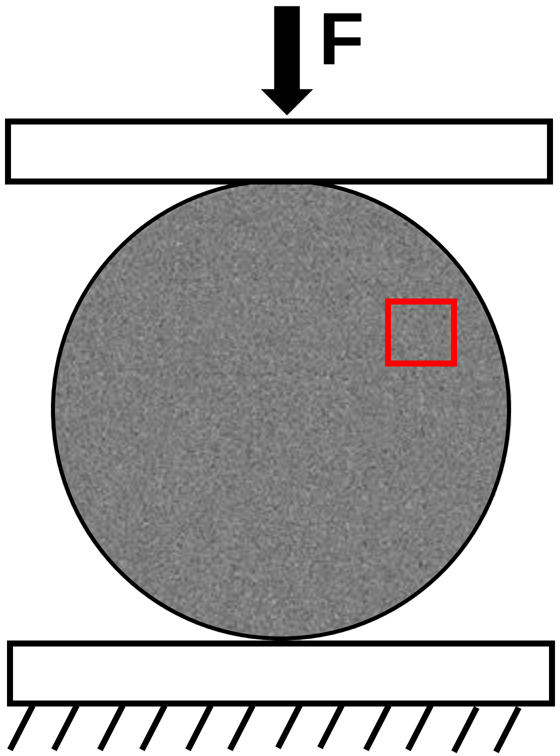


(C. Gazeau et al. – "Experimental set up for the mechanical characterization of plane ITM membrane at high temperature" – Journal of the European Ceramic Society – 2015)

1. Initial guess for the parameters of a given constitutive model
2. Numerical simulation
3. Theoretically deformed image from the reference image - Interpolation
4. Difference between experimental and theoretically deformed images
5. Convergence check
6. Calculate new material's parameters – Optimization algorithm

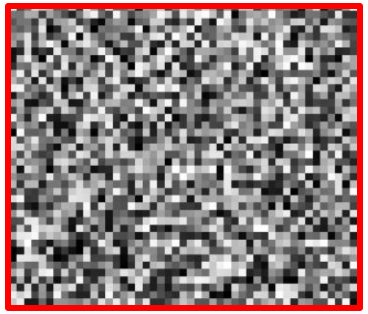
Interpolation of gray levels

Brazilian test sample



0.1 pixel

Rigid Body Motion



12
73
99

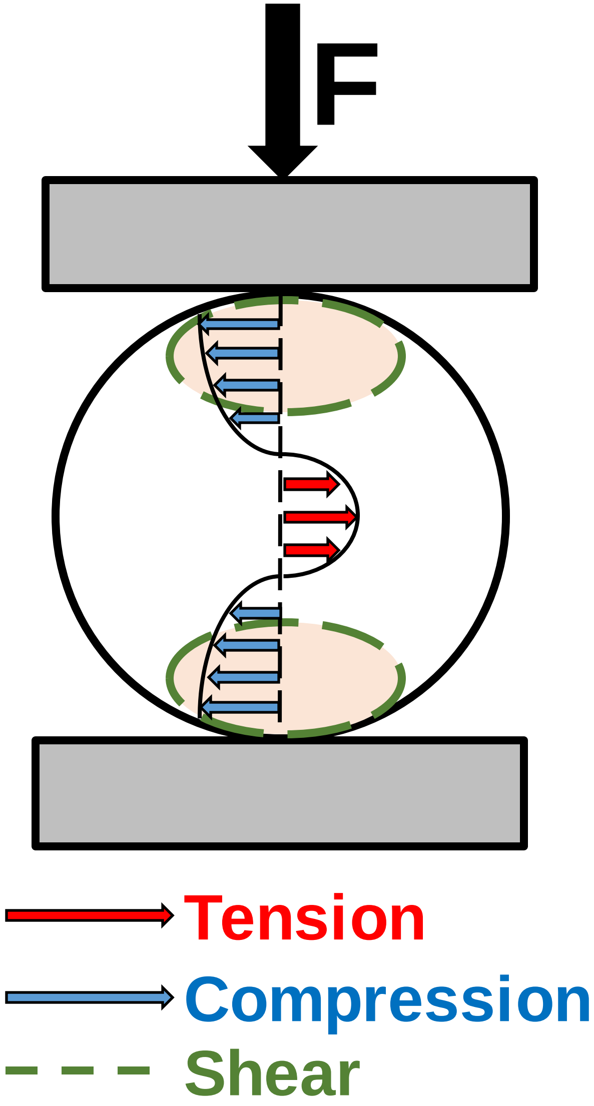
$$73 \times 0.9 + 12 \times 0.1 = 66.9$$

$$99 \times 0.9 + 73 \times 0.1 = 96.4$$

Round-off error

67
96

A note on the Brazilian test



- Compression, tension and shear loads in the sample at the same time
- Possibility to identify all the material's parameters at the same time
- Reduced number of tests when compared to unidimensional tensile and compressive tests

Asymmetric secondary creep model

Norton-Bailey creep law

$$\dot{\boldsymbol{\varepsilon}}^p = \frac{3}{2}\frac{\boldsymbol{s}}{\sigma_{eq}}\left(\frac{\langle \sigma_{eq} - \sigma_y \rangle}{K}\right)^n$$

Split of the stress tensor

$$\boldsymbol{\sigma} = \langle \boldsymbol{\sigma} \rangle - \langle -\boldsymbol{\sigma} \rangle$$

Asymmetric viscoplastic strain rate

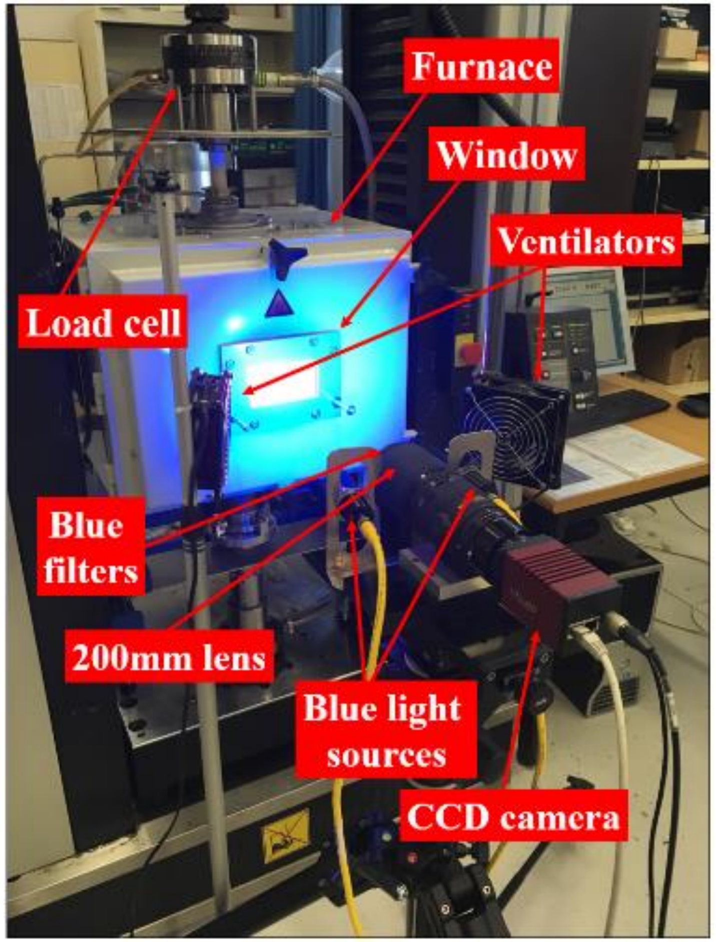
$$\dot{\boldsymbol{\varepsilon}}^p = \frac{3}{2}\frac{\boldsymbol{s}^+}{\sigma_{eq}^+}\left(\frac{\langle \sigma_{eq}^+ - \sigma_y^+ \rangle}{\boldsymbol{K}^+}\right)^{\boldsymbol{n}^+} - \frac{3}{2}\frac{\boldsymbol{s}^-}{\sigma_{eq}^-}\left(\frac{\langle \sigma_{eq}^- - \sigma_y^- \rangle}{\boldsymbol{K}^-}\right)^{\boldsymbol{n}^-}$$

(E. Blond et al. – "Modelling of high temperature asymmetric creep behavior of ceramics" – Journal of the European Ceramic Society – 2005)

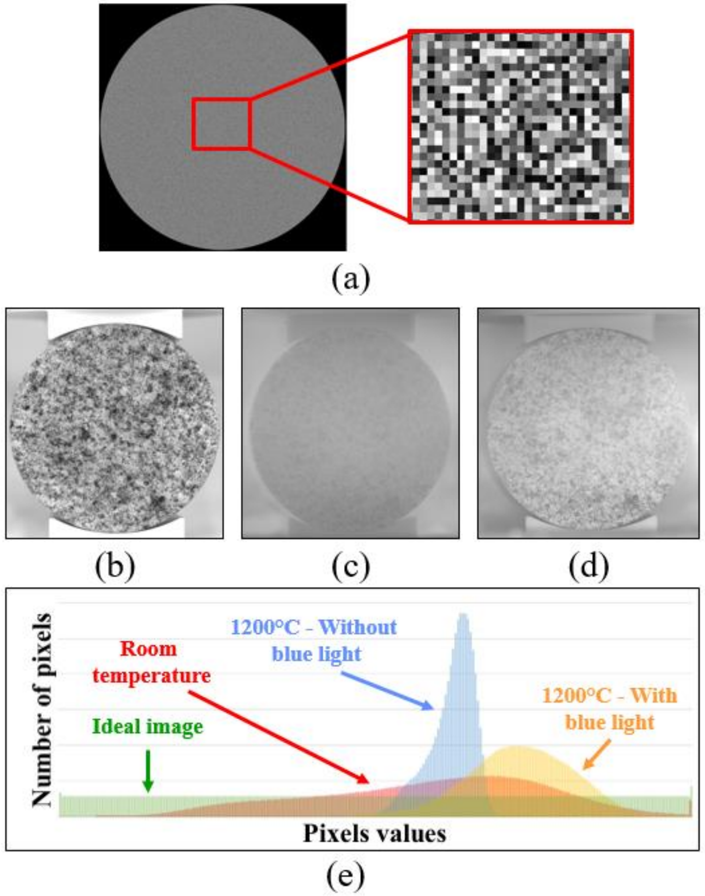
where:

- $\boldsymbol{s}$ ⟶ Deviatoric stress tensor
- σ_{eq} ⟶ Von Mises equivalent stress
- σ_y ⟶ Yield stress
- K, n ⟶ Material's properties
- $+/-$ ⟶ Indexes related to tension and compression behavior

Experimental setup



High temperature experimental setup

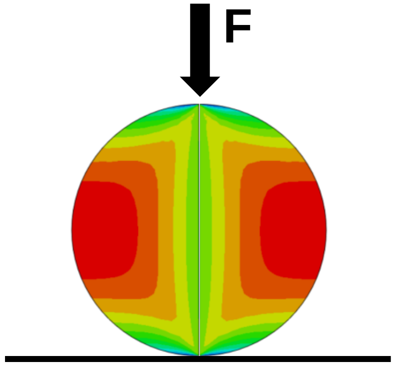


Brazilian test samples used with I-DIC. (a) Virtual image. (b) Room temperature. (c) 1200° C without using the blue lights. (d) 1200° C using the blue lights. (e) Images' histograms.

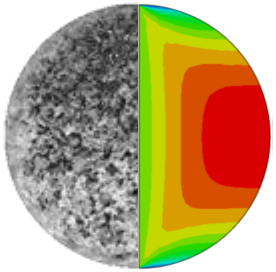
Methodology

Virtually deformed images were used to test the suitability of the I-DIC technique in the identification of asymmetric creep parameters

Step 1
Perform a numerical simulation with known materials' properties



Step 2
Impose the deformation field to a reference image taken at 1200°C



Step 3
Initialize the algorithm using an initial guess which is different for the actual solution

Step 4
Using the I-DIC algorithm, try to identify the material's parameters initially imposed

Results

$$\dot{\boldsymbol{\varepsilon}}^p = \frac{3}{2}\frac{\boldsymbol{s}^+}{\sigma_{eq}^+}\left(\frac{\langle\sigma_{eq}^+ - \sigma_y^+\rangle}{K^+}\right)^{n^+} - \frac{3}{2}\frac{\boldsymbol{s}^-}{\sigma_{eq}^-}\left(\frac{\langle\sigma_{eq}^- - \sigma_y^-\rangle}{K^-}\right)^{n^-}$$

Reference values for the material's properties

K^+	5773.5 $MPa\ s^{1/n}$
n^+	2
K^-	$1 \times 10^6 MPa\ s^{1/n}$
n^-	1.5

Use of a Genetic algorithm to perform the optimization

Solution 1

	Value	Error
K^+	5127.6	-11.19%
n^+	2.01	0.27%
K^-	9.71×10^5	-2.91%
n^-	1.51	0.71%

Solution 2

	Value	Error
K^+	5543.3	-3.99%
n^+	1.99	-0.46%
K^-	1.25×10^6	-24.97%
n^-	1.48	-1.10%

Solution 3

	Value	Error
K^+	5264.7	-8.81%
n^+	1.99	-0.58%
K^-	1.08×10^6	8.14%
n^-	1.51	0.35%

Conclusions

- Refractory materials present complex mechanical behavior, and it's important to consider viscoplastic strains for the prediction of the lining operational time

- Traditional unidimensional creep tests have showed to be an interesting way to characterize refractory materials, but many tests are required

- The combination of I-DIC with Brazilian tests was proposed to reduce the number of tests required, as well as to create a close relation between the identification process and the numerical models

- I-DIC was shown to be a suitable technique to be applied to refractories at high temperatures

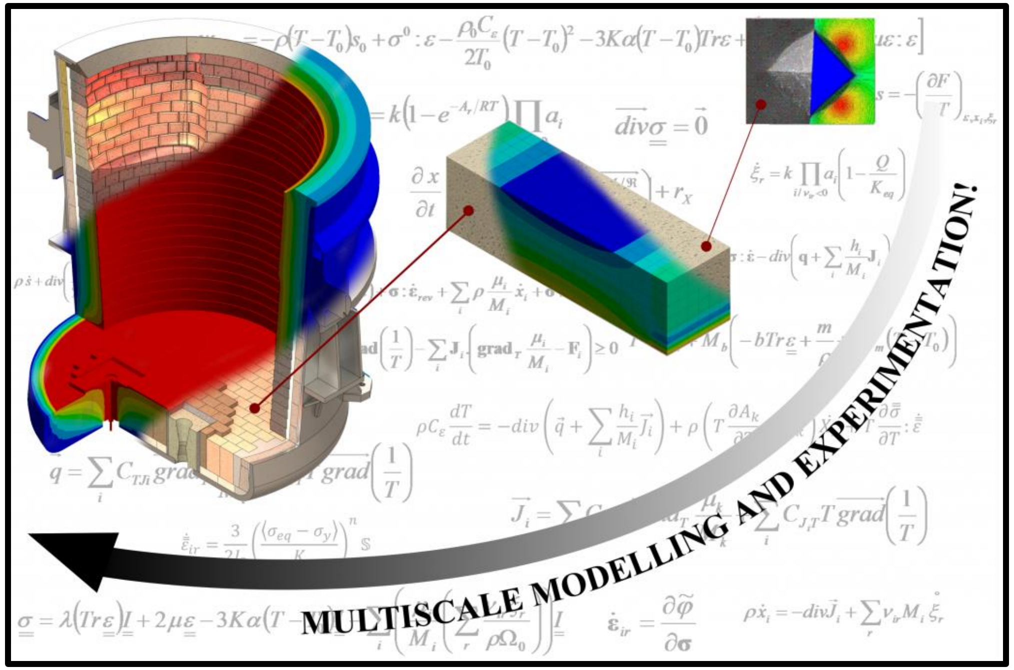
Next steps

- Perform Brazilian tests at high temperatures and use the I-DIC technique to identify the creep parameters – On going

- Compare the identification results with the ones obtained using unidimensional tension and compression tests (already performed in cooperation with Montanuniversität Leoben – Austria)

- Validation tests – Four-points bending

- Test the suitability of different creep laws for the materials being studied:
  - Primary creep law with isotropic hardening
  - Primary creep law with kinematic hardening – creep transients



www.etn-athor.eu

Thank you for your attention

lucas.breder-teixeira@univ-orleans.fr

European Commission | Horizon 2020 European Union funding for Research & Innovation

MARIE CURIE ACTIONS

ATHOR EU MSCA ETN Refractory linings

www.etn-athor.eu

Acknowledgments: this work was supported by the funding scheme of the European Commission, Marie Skłodowska-Curie Actions Innovative Training Networks in the frame of the project ATHOR - Advanced THermomechanical multiscale modelling of Refractory linings 764987 Grant.