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Further Characterization of Irradiated Steels by Indentation at High Temperature

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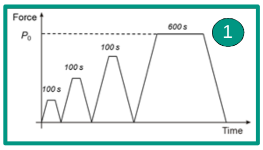
Motivation

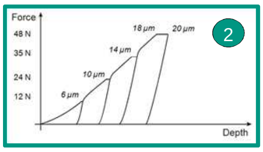
*Characterization of **hardening**, **embrittlement** and **recovery** effects in irradiated metals (at a constant dose) has been achieved by the **technique of indentation** using a neural networks based post-analysis program. Indentation experiments were performed at room temperature by means of a commercial machine (Zwick Z2.5) located in a lead-shielded **Hot Cell** of the FML, while a new indentation device has been designed with a view to further investigate **RAFM** and **ODS-RAFM** steels up to their operating temperature limits of **650 ℃** in fusion reactors.*

Characterization at Room Temperature by Instrumented Indentation

Materials of Interest: RAFM steels (Eurofer97)

Experimental Approach:





Force-controlled tests
- Unloading phases
- Different holding times for creep phases
- Uniform load steps

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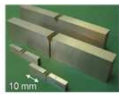
→ Experimental indentation curve used as input data for the extraction of mechanical properties 2

→ Assessment of mechanical material properties by the post-analysis tool (Neural networks-based programme)

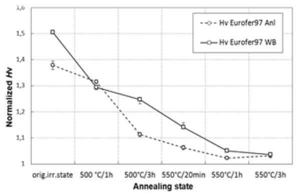
*Multiple cycles-loading tests are required for the **neural networks-based analysis tool** [1] to notably calculate the material's strength. A post-treatment of experimental data is carried out from the indentation curve (force versus indentation depth) by the neural networks-based method to identify the **materials properties** such as Young´s modulus, yield strength, viscosity parameters,... Additionally, the material´s **hardness** is directly derived from standard Vickers hardness tests at 20N.*

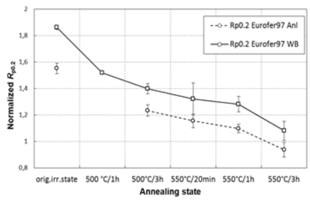
tested specimens: miniaturized V-notched broken halves



Analysis of Post-irradiation Annealing:

*Eurofer97´s **H_v** and **$R_{p0.2}$** start to **recover** for 500℃/ 20min. The effect of the annealing temperature of **550 ℃** is found to be more pronounced than in the case of the two tested conditions at 500 ℃. Both Eurofer97 Anl and Eurofer97 WB almost reach their original hardness and yield strength states after 3 hours heating at 550 ℃. Additionally, the post-irradiation heat treatment show that Eurofer97 Anl is generally less affected by the irradiation-induced damage than Eurofer97 WB.*

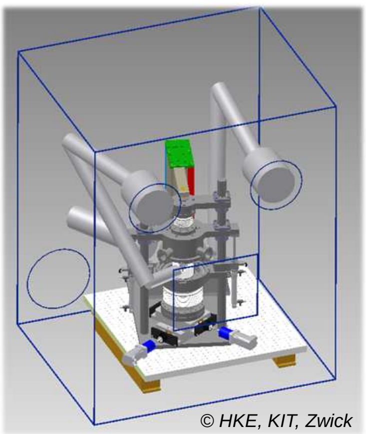




all tested samples Eurofer97 @ Tirr= 250 °C and 15 dpa
(data normalized to the unirradiated state)

Development of an Indentation Insrument for Tests at High Temperature

Design of the Indentation Device for a Use in the FML Hot Cell



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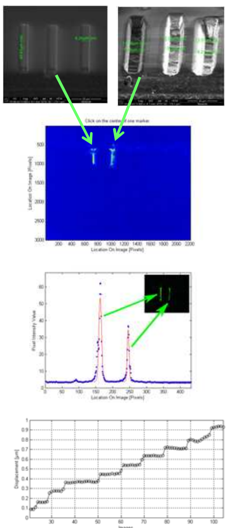
*The whole testing device was designed to be inserted in a **FML Hot Cell**. The machine is mainly featured by a vacuum chamber used for **high vacuum** testing conditions, a water cooled XY positioning stage, and a heating system making use of **cartridge resistors** located at the sample and the indenter. It is also carried by an active anti-vibration stage for a better accuracy regarding the adapted **optical setup** used for indentation depth measurement.*

Process used for the Measure of Indentation Depths

*The **optical setup** is featured by a long working distance microscope associated with a digital camera and an image processing tool based on the **DDIT** (Differential Digital Image Tracking) technique [2]. This measuring technique was selected according to its ability to measure displacement occurring at high temperature with **nanoscale resolutions** and in room temperature conditions.*



Manufacturing of adapted markers by the Focused Ion Beam technique (Platinum deposition or engraving at the indenter location)

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Light extraction of laser illuminated markers by the DDIT tool (pixel´s brightness analysis)

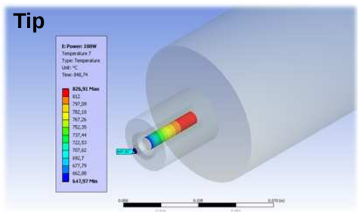
↓

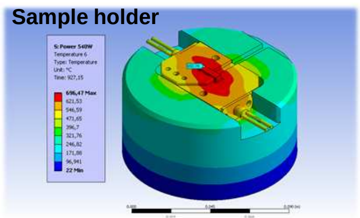
Analysis of markers position by use of a mathematical function describing the pixel brightness as a function of pixel location

↓

Measurement of markers displacement (highest achieved displacement resolutions: from 20 nm to 100 nm)

Development of a Heating system for the Sample and the Tip





*Both the **sample** and the **tip** are heated by means of **cartridge resistors** in order to avoid substantial heat flow due to a temperature gradient when the contact occurs and related thermal expansion. Numerical thermal analyses show that an electrical power of 100 W and 540 W is needed to heat respectively the indenter and the sample up to **650 ℃** within approximately 15 min.*

Literature

[1] N. Huber et al., J. Nucl. Mater., 377, 2008, 352-358.
[2] W.N. Sharpe Jr. et al., Exp. Mech. 47, 2007, 649-658

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