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Effect of neutron irradiation to 0.7 and 1.4 dpa on the tensile mechanical properties and microstructure of EUROFER97 steel

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ABSTRACT

Several grades of reduced-activation ferritic-martensitic (RAFM) steels have been proposed for fusion applications (e.g., blanket first wall) since the 1990s all over the world. Four batches of the European reference RAFM steel EUROFER97 have been produced since 1998. The RCC-MRx design code, developed, among others, for fusion reactors, currently contains a provisional section dedicated to EUROFER97, encompassing properties of the first two batches, whereas minimum three batches are required for a full qualification and final inclusion of a material into RCC-MRx. The EUROfusion project coordinates efforts to broaden the knowledge of EUROFER97 properties relevant for fusion reactors ITER and DEMO, preparing them for closing the database gaps in RCC-MRx and aggregating them in the DEMO material property handbook (MPH). Its purpose is to provide average and minimum curves of required properties according to the DEMO engineering design and manufacturing needs.

The present work reports mechanical properties and fractographic analysis of batch 4 of neutron-irradiated EUROFER97 for the first time. The measured strength and ductility are in line with the data already aggregated in the MPH. SEM investigation confirms that the dimple fracture is retained in the material after neutron irradiation up to 1.4 dpa in the temperature range 25…550 °C.

Video and Transcript to this article can be found online at https://doi.org/10.1016/j.sctalk.2023.100214.

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Figures and tables

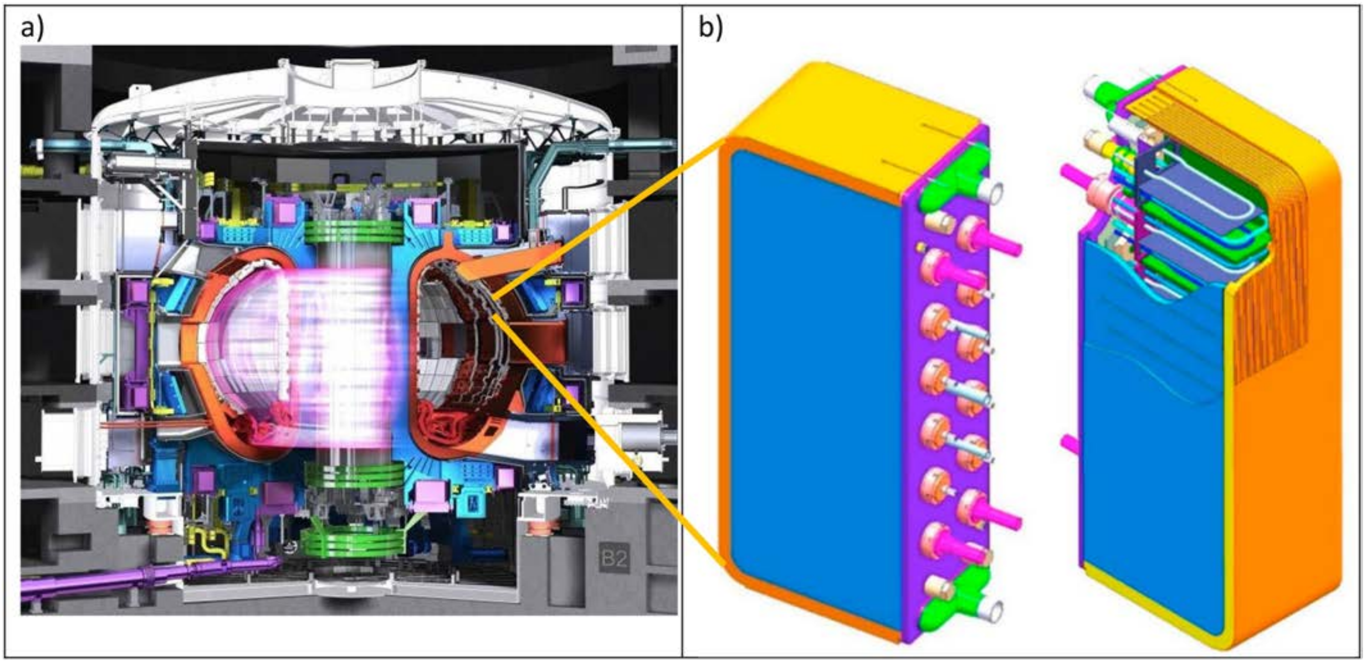

Fig. 1. (a) A cut of the 3D model of ITER, the world's largest fusion reactor under construction in France [iter.org]. (b) Design of the water cooled lithium-lead (WCLL) test blanket module (TBM) for ITER, which will be made of EUROFER97 [1].

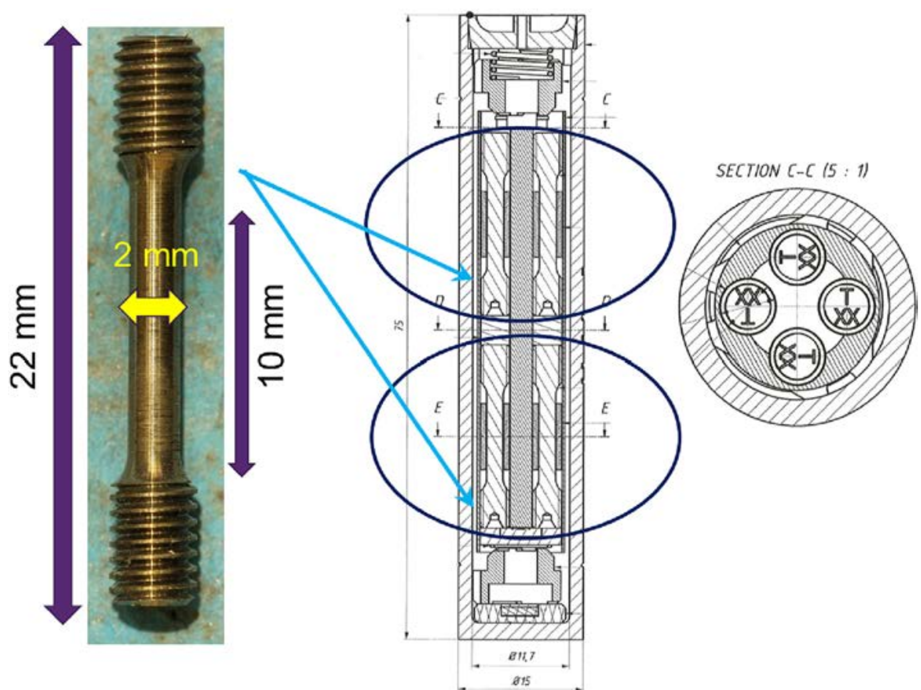

Fig. 2. Example and dimensions of the tensile specimens used in the present research (left) and a drawing of their positioning in irradiation capsules for the BR-2 reactor (center and right).

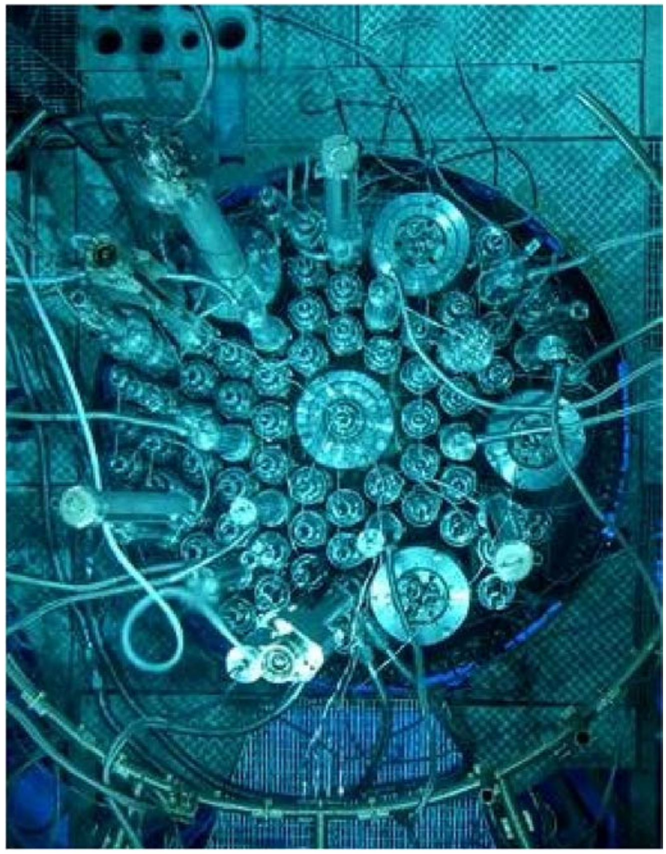

Fig. 3. Top view of the irradiation channels of the BR-2 material test reactor at SCK CEN (Belgium) [sckcen.be].

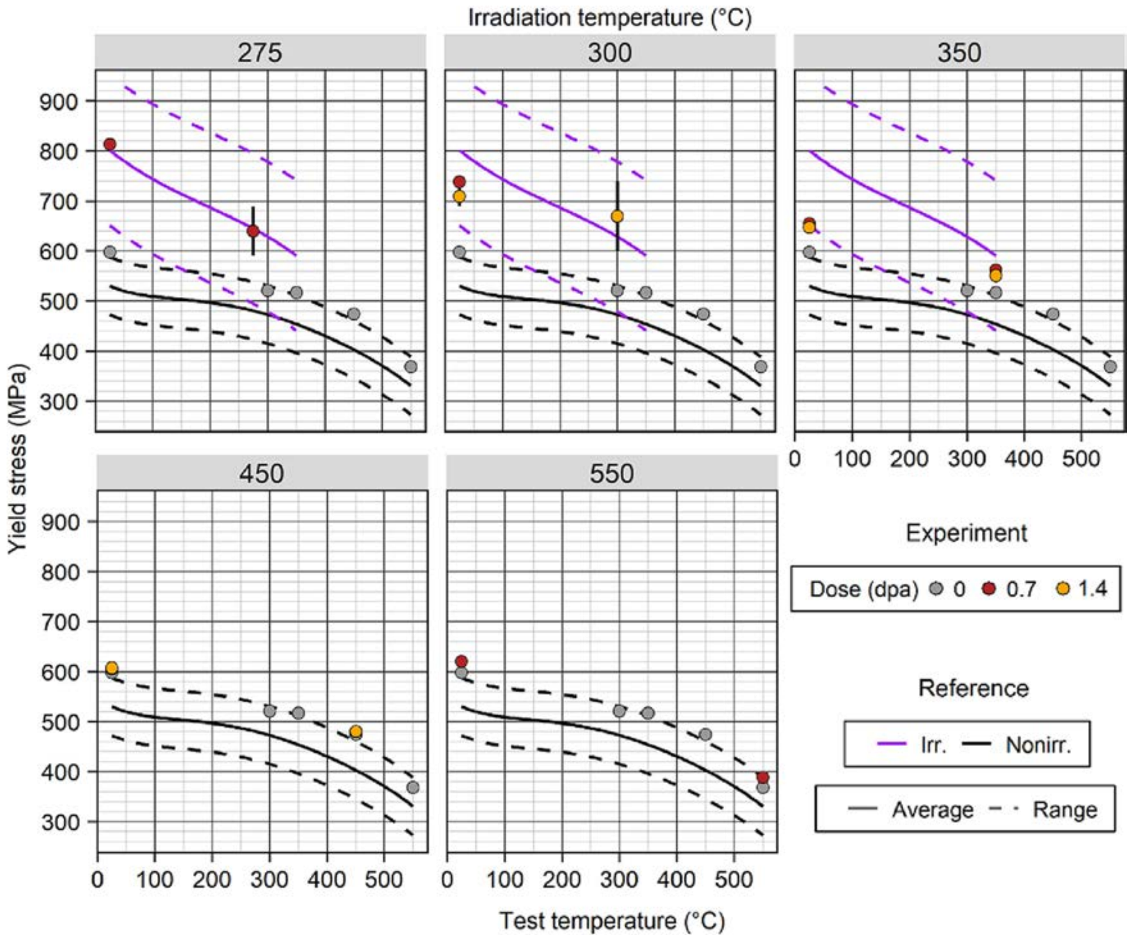

Fig. 4. Yield stress (mean) of EUROFER97 batch 4 before and after neutron irradiation compared to the reference data [2,3].

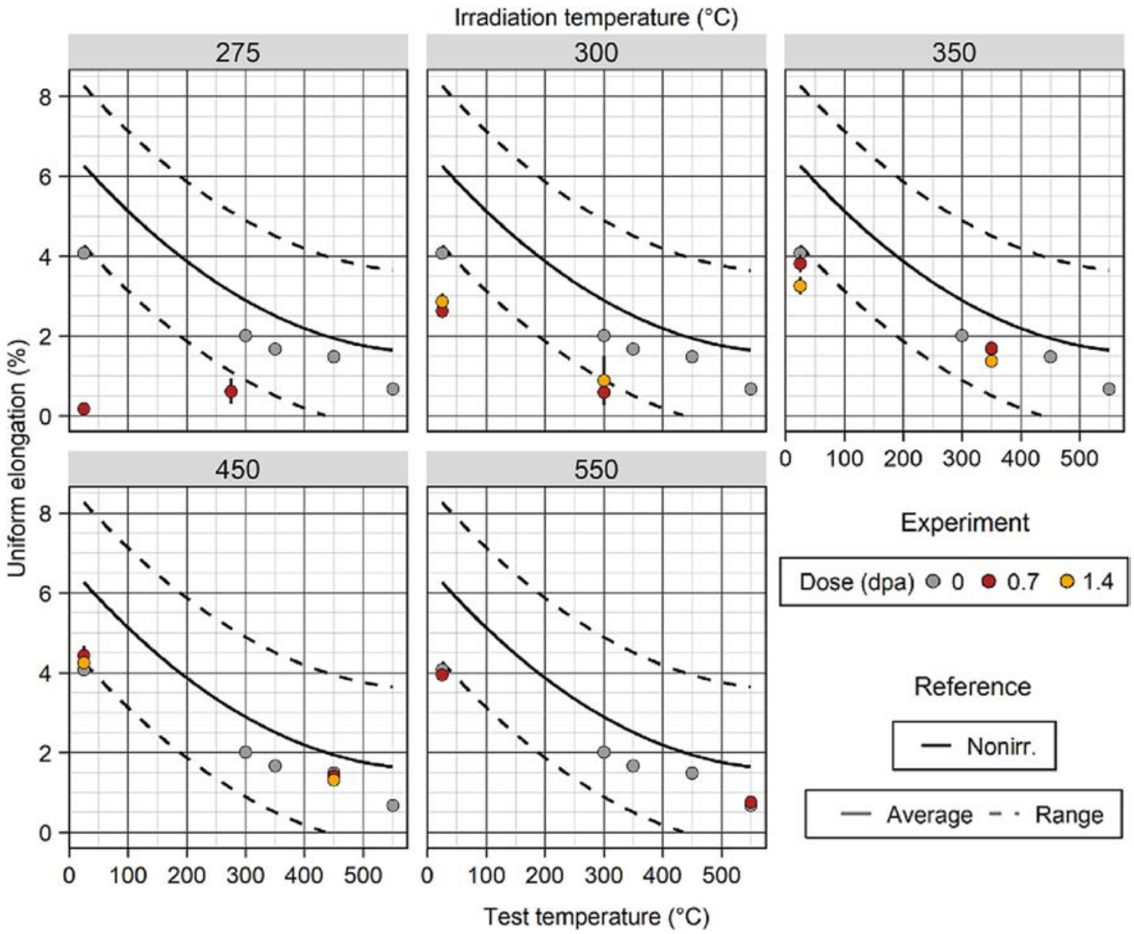

Fig. 5. Uniform elongation (mean) of EUROFER97 batch 4 before and after neutron irradiation compared to the reference data [3].

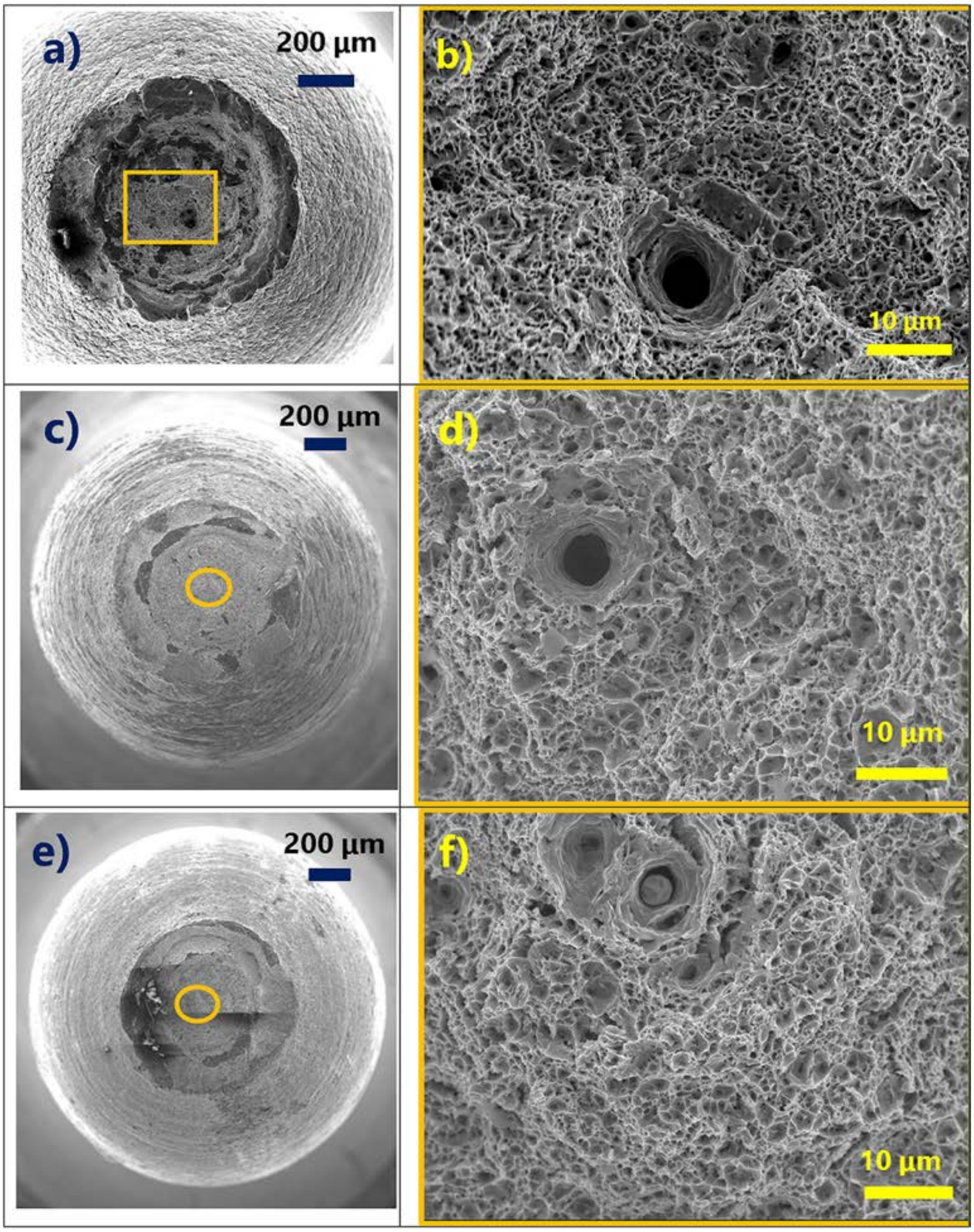

Fig. 6. Fracture surface of tested tensile specimens of EUROFER97 batch 4 tested at room temperature. Left panels – general view of the specimen cross-section. Right panels – high magnification images taken from the area marked on the left images. (a, b) Nonirradiated. (c, d) Irradiated to 1.4 dpa at 300 °C. (e, f) Irradiated to 0.7 dpa at 550 °C.

CRediT authorship contribution statement

Aleksandr Zinovev: Investigation, Visualization, Writing – original draft, Writing – review & editing. **Chih-Cheng Chang:** Investigation. **Jelle Van Eyken:** Investigation, Visualization. **Ermile Gaganidze:** Conceptualization, Methodology, Validation, Resources, Writing – review & editing. **Dmitry Terentyev:** Supervision, Project administration, Funding acquisition.

Data availability

Data will be made available on request.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Further reading

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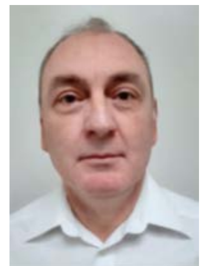

Ermile Gaganidze received his Diploma in Physics from Ivane Javakhishvili Tbilisi State University. He earned his PhD degree from the University of Bayreuth. He worked as a scientist at Institute of Physics of the Georgian Academy of Sciences, University of Bayreuth and University of Leipzig. In 1998 he joined the Karlsruhe Institute of Technology (KIT). Currently he is a senior scientist at KIT at the Institute for Applied Materials – Mechanics of Materials and Interfaces leading a group investigating the neutron irradiation induced damage in the structural materials for fusion application.

Dmitry Terentyev has obtained master degree in Nuclear Physics in 2002 at Saint Petersburg Polytechnic University, followed by the PhD degree in 2006 issued at Université Libre de Bruxelles. Since 2014, Dr. Dmitry Terentyev leads the Fusion Research Programme at Belgian Nuclear Research Center (SCK CEN, Mol). Scientific expertise of Dr. Terentyev covers materials science, neutronic physics and computational materials modelling. Specific focus of research is made on irradiation effects in nuclear materials.