Predicting irradiation hardening and microstructural evolution in irradiated Eurofer97: a nanoindentation study supported by CPFEM and TEM

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Reduced activation ferritic/martensitic (RAFM) steels are the main candidates for the construction of structural components in future fusion and Gen IV nuclear reactors. To ensure safe and stable reactor employment, RAFM-based materials require efficient methods for their characterization under harsh operational conditions. Constantly exposed to neutron irradiation, their mechanical properties degrade and may lead to component failure. However, neutron irradiation for research purposes is an expensive and time-consuming process, so it becomes a major limiting factor in steadily investigating its effects and delivering new research data. Hence, a safer, faster, and cheaper solution of ion irradiation as a tool for surrogating the neutron damage is becoming more and more popular. As ions are characterized by their penetrating ability, the introduced damage is non-uniformly distributed and densely accumulated on the sub-surface. To correctly estimate their impact, the nanoindentation technique is widely applied. The presented study demonstrates the development process of a semi-empirical approach [1] to effectively interconnect the ion and neutron radiation-induced hardening in RAFM steels, introduced in a range of irradiation conditions. The applied set of tools, based on nanoindentation and tensile tests, as well as their simulations using crystal plasticity finite element method, allows us to extract the irradiation effect on the material law, and accurately reproduce the experimental data. Ultimately, the analysis performed on an ion-irradiated specimen can provide the macroscale (neutron irradiated) yield stress values in a range of dpa doses, which accurately correlate with the literature. The complementary investigations of the microstructural evolution done by focused ion milling and transmission electron microscopy are compared with their computational analogue to confirm the predictive capability of the method. Globally, the presented research is aimed at the establishment and validation of the computationally experimental procedure to precisely deduce the temperature-dependent irradiation hardening in metallic materials for nuclear applications.

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