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PHYSICAL AND MECHANICAL EFFECTS OF RADIATION DAMAGE

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The present work focuses on the experimental analysis and the constitutive modeling of irradiation effect on mechanical properties of the materials subject in the nuclear installations design and the particle detectors.

Irradiation of materials leads essentially to severe degradation of material microstructure. In the materials, the displacements of atoms, caused by direct collisions of fast particles with the atoms, are the primary driving force of radiation defects creation. As a result of the collision cascade overlap, the creation of vacancy clusters (empty lattice sites) and/or interstitials clusters (atoms sharing lattice sites) occurs. Most of the point defects recombine within the time evolution of the displacement cascade. The remaining defects, voids, cavities, dislocation loops, and stacking-fault tetrahedral (SFTs) form stable defect configurations which are responsible for the radiation-induced microstructural changes, resulting in the evolution of the physical and the mechanical properties. All the physical processes in the irradiated materials occur during and soon after the interaction of energetic incident particles with lattice atoms. These processes are experimentally unobservable because a displacement phase of the collision cascade usually lasts even 10^{-12} seconds. The only approach that may address this issue is Molecular Dynamics (MD) simulations [1, 2]. At the atomic scale, the character and migration properties of self-interstitial clusters, dislocation loops kinetics, defect-dislocation interactions, void and gas bubble formation are studied by Molecular Dynamics simulations (Fig.1).

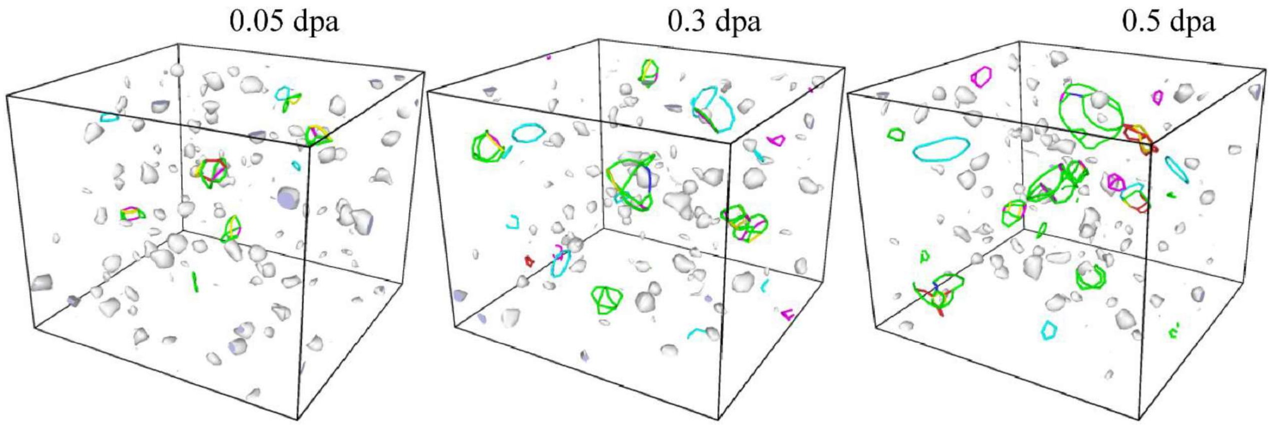

Fig. 1. Nucleation and evolution of radiation induced defects (voids, dislocation loops and stacking-fault tetrahedral formation) in austenitic stainless 310S

In order to validate molecular dynamics simulations, the ions irradiation campaign with MeV energies were carried out using a tandem accelerator in cooperation with the University of Oslo, Centre for Materials Science and Nanotechnology. Transmission electron microscopy (TEM) investigations show the structural changes resulting from the ion beam irradiation. Direct observations of the defect structure, range, and the radiation-induced defect concentrations in the studied material was determined.

At the meso- and macroscopic levels, the irradiation of materials leads to drastic modifications of mechanical properties. The magnitude of the mechanical changes depends on multiple factors related to the irradiation conditions: radiation energy, particle fluence and flux, material composition and its history. In irradiated materials, the induced defects contribute to irradiation hardening, reduction in ductility, increased embrittlement, volumetric swelling, and helium accumulation. However, plastic deformation is based on similar mechanisms like in the virgin materials. In particular, the main mechanism of plastic flow is still slip. However, due to radiation induced defects the motion of dislocations within the easy slip planes is hindered by different obstacles, causing substantial increase of the flow stress.

In this work, the radiation-induced damage is defined in the framework of Continuum Damage Mechanics (CDM) [5, 6] and peridynamics theory (PD) [3] to solve the problem of further evolution of damage fields under mechanical loading. A novel material model based on nonlocal peridynamic theory is proposed to study irradiated materials [3]. The peridynamic theory is particularly powerful in modelling problems where spontaneous formation of discontinuities, like micro-damage, voids and cracks, occurs. The experimental characterization of the deformation process of the ion irradiated materials during the nano-indentation test is carried out. The numerically obtained curves were imposed on the experimental data [5].

Moreover, in the present work a physically-based constitutive model is proposed which allows to describe the effects of creep of irradiated materials at cryogenic temperatures and the physics of defect generation [4]. The quantum tunneling as the mechanism responsible for creep deformations at sufficiently low temperatures and relatively high-stress levels is adopted. Dislocations that are locally pinned can escape from their pinning points more rapidly via tunneling than by means of thermal activation. Peierls lattice resistance mechanism is used to explain creep produced by the elastic interaction of radiation-induced point defects with existing dislocations in materials. Furthermore, assuming the quantum tunneling mechanism, the kinetic law for the evolution of irradiation-induced dislocation loops is proposed. Predicted creep rate behavior as a function of stresses and *dpa* are presented.

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