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DEGRADATION OF MATERIAL PROPERTIES DUE TO EVOLUTION OF RADIATION INDUCED DAMAGE

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General

The problem undertaken in the present work concerns the kinetics of evolution of radiation induced damage under mechanical loads. Furthermore, coupling between the radiation induced nano-damage and the mechanically induced micro-damage is taken into account. During irradiation, energetic particles penetrating a solid displace the lattice atoms from their original positions. Exposure to a flux of particles leads inevitably to creation of clusters of defects in the material, provided that the energy of incident particles is large enough. Collisions of particles of enhanced energy with the lattice atoms ejects the atoms from their initial position and transfers the energy to the next collisions with the neighboring atoms. These atomic interactions lead to creation of the cascade of atoms moving inside lattice and to production of radiation induced defects in the lattice. Thus, as a result of the cascade process, the pairs of interstitial atoms and vacancies (the so-called Frenkel pairs) are created [3]. The evolution of radiation induced damage is combined with the evolution of classical mechanically induced damage within the common framework of Continuum Damage Mechanics (CDM). An additive formulation with respect to damage parameters or tensors has been used. A multiscale constitutive model comprising the evolution of radiation induced damage under mechanical loads has been formulated [1]. Two kinetic laws of damage evolution were taken into account: the Rice and Tracey model and the Gurson model. Both of them address the evolution of porosity in the form of spherical or ellipsoidal voids in a different way. The Rice & Tracey model predicts the evolution of radius of spherical void as a function of triaxiality $\left(3\sigma_m / 2\sigma_{eq}\right)$ and the equivalent plastic strain dp. The Rice & Tracey model [5] is expressed in the form of differential equation:

$$dr_c = r_c \alpha_r \exp\left(\frac{3\sigma_m}{2\sigma_{eq}}\right) dp \,. \tag{1}$$

Thus, in order to obtain the radius increment dr_c a differential equation has to be solved and the current radius can be updated. In order to compute the damage parameter, the volume or the surface density of voids has additionally to be known. On the other hand, the Gurson model [2] is based on the definition of the porosity parameter ξ:

$$\dot{\xi} = (1-\xi)\dot{\varepsilon}_{kk}^{p} \,, \tag{2}$$

where $\dot{\varepsilon}_{kk}^{p}$ denotes trace of the plastic strain rate tensor. The porosity parameter can be directly recalculated to obtain the classical damage parameter in the sense of CDM. Here, a simple differential equation has also to be solved in order to obtain the porosity increment. Both Rice & Tracey and Gurson kinetics may conveniently be applied to describe the evolution of radiation induced damage in the form of clusters of voids embedded in the metallic matrix [4,6]. As an application, estimation of lifetime of coaxial target embedded in a particle detector configuration, subjected to combination of irradiation and mechanical loads, has been carried out (Fig. 1).

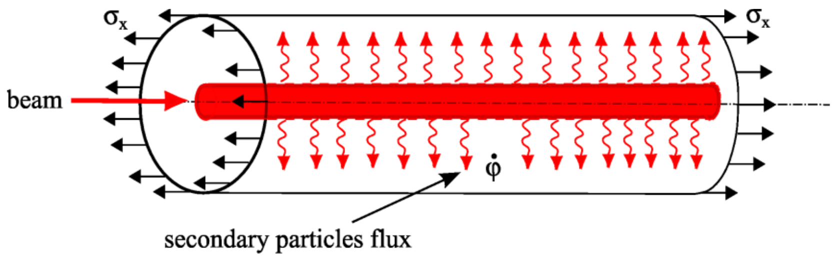

Fig. 1. Coaxial target – detector configuration (round bar and cylindrical shell)

The shell is subjected to pulsed irradiation by the flux of secondary particles generated by solid target located coaxially and hit periodically by high energy particles beam. In addition, the shell is subjected to cyclic mechanical loads which leads to build-up of cyclic stress state containing localization. Combined radiation and mechanical loads lead to evolution of both damage components as a function of the number of cycles (time). The lifetime prediction has been expressed in terms of number of beam cycles as a function of maximum *dpa* (displacement per atom) on cycle [7]. New closed form analytical solutions for the problem of periodic irradiation combined with cyclic axial load, and corresponding to Rice & Tracey and Gurson models were obtained.

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