Kinetics of evolution of radiation induced micro-damage in ductile materials subjected to time-dependent stresses

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The problem undertaken in the present work concerns constitutive modelling of evolution of radiation induced micro-damage in the solids subjected to mechanical loads beyond the yield stress. The model has been developed in the framework of Continuum Damage Mechanics (CDM), and contains strong physical background related to the mechanism of generation of clusters of voids in the irradiated solids. 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 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. The vacancies of the Frenkel pairs often accumulate in clusters by means of diffusion. The evolution of radiation induced damage is combined with the evolution of classical, mechanically induced damage, within the common framework of 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]. The tensorial representation of the radiation induced damage reads:

$$\underline{\underline{D}}_{rm} = \frac{1}{3} D_{rm} \underline{\underline{I}} \ , \tag{1}$$

where $\underline{\underline{I}}$ denotes the identity tensor. In order to combine both types of damage: radiation induced and of mechanical origin, additive rule is postulated. The total damage tensor is constructed as a sum of the radiation and mechanically induced damage tensors:

$$\underline{\underline{D}} = \underline{\underline{D}}_m + \underline{\underline{D}}_{rm} = \underline{\underline{D}}_m + \frac{1}{3} D_{rm} \underline{\underline{I}} \ . \tag{2}$$

Kinetics of radiation induced damage involves two models, describing the evolution of porosity in the materials: the Rice &Tracey (R&T) and the Gurson models[2]. The R&T model predicts the evolution of radius of a spherical void as a function of the triaxiality and the accumulated plastic strain. The R&T model is expressed in the form of differential equation and has, therefore, implicit character. Thus, in order to obtain the radius increment 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 is based on the definition of the porosity parameter. 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 R&T 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. New closed form analytical solutions were obtained.

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1 Skoczeń and Ustrzycka, *International Journal of Plasticity*, (2014), (under review)

2 Nahshon and Hutchinson, *Eur. J. Mech. A/Solids*, **27** 1-17, (2008)