Development of a polycrystalline approach for the modelling of high cycle fatigue damage: Application to a HSLA steel

For many metallic alloys, fatigue crack initiation is governed by the development of a localized plastic activity at the grain scale. Because of the irreversible nature of plasticity, a significant proportion of the total work is dissipated into heat during a cyclic loading. As a consequence, one may expect some correlation between heat dissipation and high cycle fatigue damage as both phenomena are closely related.

The purpose of the present work is to study such correlation for a ferritic high strength low alloyed steel subjected to various cyclic loading conditions. For several uniaxial fatigue tests carried out under different load ratios and stress levels, an experimental dataset consisting of stress, strain and temperature measurements is used to estimate the evolution of the amount of dissipated energy. A clear correlation between dissipated energy and the number of cycles to failure is observed.

Based upon these experimental observations, a constitutive model, which assumes fatigue damage to be driven by plasticity, is proposed. To account for the anisotropy of elastic and plastic properties, the model is developed within a rate-dependent crystal plasticity framework. Some internal variables are introduced for each slip system to describe isotropic hardening, kinematic hardening and fatigue damage. The dependence of the elastic stiffness tensor regarding the damage variables and the orientation of the associated slip systems allows accounting for the anisotropic nature of fatigue damage. The definitions of the driving forces associated with the internal variables are derived from a phenomenological energy potential. For the specific case of damage, the driving force is found to be strongly related to stored energy. To account for the polycrystalline nature of the material, the constitutive model is then implemented within a self-consistent formulation. The model is used to investigate the fatigue behavior of the ferritic high strength low alloyed steel. The representative volume element consists of about 600 grains whose orientations were selected to be consistent with the experimental crystallographic texture. The model coefficients are identified using the results obtained from stress-controlled fatigue tests with different amplitudes and mean values (respectively R=0.1 and R=0.3).

Finally, the model is used for gaining insight into the microscopic scale. It allows for estimating the amount of energy which is either stored in the material or dissipated into heat at the grain scale. Damage is found to be highly localized in some specific grains with important quantities of local stored energy.