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On a computational framework to model material degradation due to moisture, temperature, and chemical reactions

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ABSTRACT

Degradation is a major, widespread, and an important engineering problem. Its manifestations have been well known in infrastructure and various other real-life applications. This can be attributed to the fact that not only the durability of materials will be reduced, but also the material properties can be affected. For instance, thermal conductivity and diffusivity can change its behavior from isotropic to anisotropic because of the influence of material damage. Degradation can be caused by various mechanisms such as mechanical processes, chemical dissolution, oxidation, photolysis, biological effects, and radiation. Moreover, coupling effects between these mechanisms can have a significant impact on the rate of deterioration of materials and structures. Therefore, developing an appropriate framework to model material degradation is very useful to predict the life span of a given structure. Hence, a comprehensive knowledge on the effects of degradation not only plays a pivotal role in improving the reliability of existing infrastructure, but also has a tremendous impact on the economy. However, it should be noted that developing a unified thermodynamic and computational framework to encompass the above set of mechanisms for material degradation is still an open problem. Furthermore, the governing equations to model even a simple degradation mechanism such as moisture or thermal by-itself is complicated and difficult to construct. In this discussion, we shall assume that predominant degradation mechanisms are moisture/chemical reactions and temperature and aim to propose a general a three-way strongly coupled degradation model based on a thermodynamic framework. In general, there are two approaches to build a thermodynamically consistent degradation model. The first one is based on the theory of internal variables. In this method, one models degradation using an internal variable. The second method is to investigate the dependence of material properties on concentration and temperature. The main disadvantage of the first approach is that it is difficult (or sometimes impossible) to measure the internal variables via experiments. However, the second methodology can compensate it. Moreover, the degradation parameters based on the second approach have a physical basis as compared to the first method. Hence, in this discussion, we shall use the second approach to construct a thermodynamically consistent degradation model in which all the damage parameters can be measured in experiments. It should be noted that the resulting governing equations for the proposed degradation model are coupled and highly nonlinear. In many cases, obtaining analytical solutions is extremely difficult. Consequently, we shall describe a numerical framework to solve such coupled nonlinear partial differential equations. Employing this computational framework, we shall solve representative boundary value problems pertaining to degradation of slabs. We shall also compare the behavior of an infinite degrading slab with the behavior of a finite-sized degrading slab. This highlights the limitations of the typical semi-inverse solutions, which are commonly employed in engineering and design practice. Finally, through such numerical examples, we shall shed light on the load carrying capacity and structural response of degrading structural members, which is vital for better design and safety codes.