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Architecture and Internal Material Length Scale: Fatigue Crack Growth Across Weak Interfaces

Josh Pribe
Purdue University, jpribe@purdue.edu

Thomas Siegmund

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Architecture and internal material length scale: fatigue crack growth across weak interfaces in layered materials

Joshua Pribe[1], Thomas Siegmund[1],
(1) Department of Mechanical Engineering, Purdue University, West Lafayette, Indiana, USA,
jpribe@purdue.edu, siegmund@purdue.edu

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Architectured materials are defined by well-controlled geometry of the microstructure. Geometry alone, however, does not define the material system response, and the dimensions of the microstructure geometry relative to those intrinsic to the material system of concern must be considered. In metals, a key material length scale is the intrinsic length for strain gradient plasticity, which accounts for the influence of geometrically necessary dislocations on the flow stress. As a result, continuum plasticity formulations enhanced with an intrinsic material length are capable of describing size effects associated with nonuniform plastic deformation on the order of microns.

One relevant situation where plastic strain gradients must be considered is fatigue crack growth toward a sharp interface between metals with a yield strength mismatch. Experiments have shown that a fatigue crack beginning in the plastically soft material may arrest and bifurcate as it approaches the interface with the plastically hard material. However, at higher applied loads, the crack may penetrate the interface [1]. Numerical simulations of this situation demonstrate that large plastic strain gradients develop when the crack tip plastic zone interacts with the interface, as seen in Figure 1. Models that account for these plastic strain gradients predict additional hardening relative to classical plasticity models, leading to an increased crack driving force. Strain gradient plasticity models therefore predict a greater likelihood that the crack will penetrate the interface rather than arresting [2].

In this contribution, we extend these results to a multilayer metallic structure consisting of a soft interlayer and a hard matrix phase bonded by weak interfaces, as shown in Figure 2. This configuration has been shown experimentally to reduce crack growth rates and thereby increase the fatigue resistance of the structure due to the yield strength mismatch [3]. We describe the metallic phases by a conventional mechanism-based strain gradient plasticity constitutive model [4], and account for fatigue crack growth across each phase and along the interfaces using cohesive zones with irreversible damage accumulation under cyclic loading. The multilayer structure possesses both geometric and material length scales, including the interlayer thickness, the strain gradient plasticity intrinsic length, and the crack-tip plastic zone size. The interactions between these length scales determine the predicted system response and, in particular, the crack path and crack growth rates near the interfaces.

We investigate the ratio of the interlayer thickness to the plasticity intrinsic length scale as well as the effect of the yield strength mismatch between each phase. We demonstrate that for conditions where the layer thickness to intrinsic length scale ratio is large and plastic strain gradients play little role, the retardation effects of the weak interface are significant, as the crack deflects into the interface. However, for thin interface layers where plastic strain gradients are stronger and lead to significant hardening, the weak interface has less of an effect on the crack growth rate. In this case, the crack penetrates the interlayer as the plastic zone cannot fully develop. We also show that, although a yield strength mismatch between the phases is necessary for the crack to deflect, this induces highly nonuniform plastic deformation near the interfaces. Similar to the results for the single interface described previously, this nonuniform deformation leads to increased hardening in the strain gradient plasticity model and a higher driving force on the crack as it propagates through the interlayer and penetrates back into the hard material. The key conclusion from this study is that the internal material length scale for strain gradient plasticity must be considered when predicting the effectiveness of multilayer materials for increasing fatigue crack growth resistance.

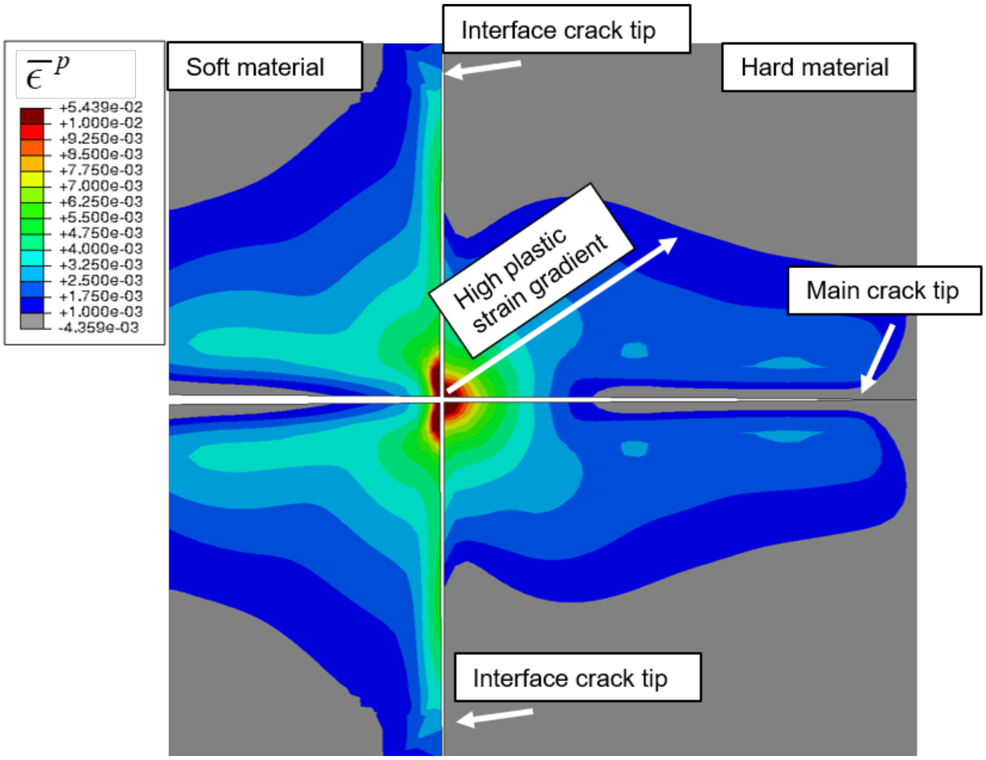

Figure 1: Equivalent plastic strain contours for fatigue crack growth from a soft material to a hard material. Note the high accumulated plastic strains and the nonuniform strain field in the region where the main crack penetrates the interface.

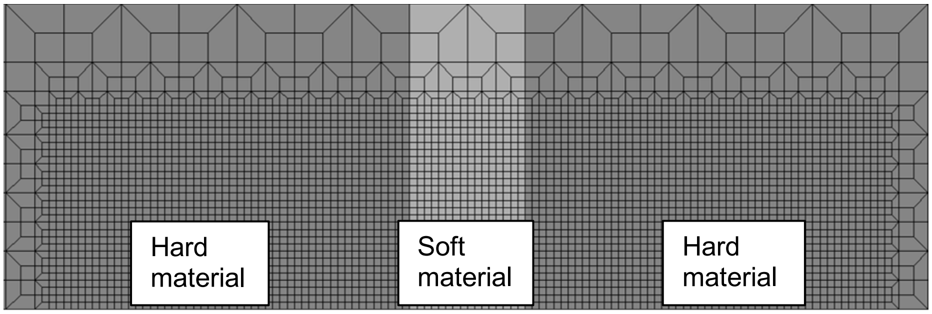

Figure 2: Interlayer model geometry.

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[1] Pippan R, Flechsig K, Riemelmoser FO. Fatigue crack propagation behavior in the vicinity of an interface between materials with different yield stresses. Mater Sci Eng A 2000;283:225–33.
[2] Pribe J, Siegmund T, Kruzic J. 2018, in preparation.
[3] Kolednik O, Zechner J, Predan J. Improvement of fatigue life by compliant and soft interlayers. Scr Mater 2016;113:1–5.
[4] Huang Y, Qu S, Hwang KC, Li M, Gao H. A conventional theory of mechanism-based strain gradient plasticity. Int J Plast 2004;20:753–82.