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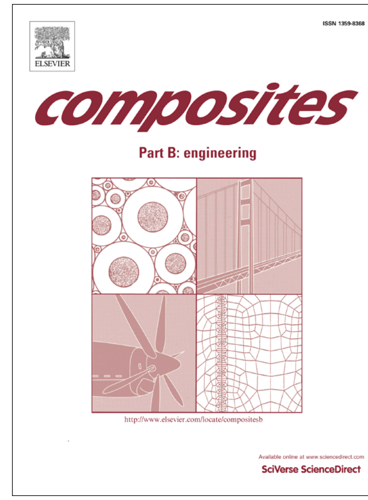

A mesomechanical analysis of plastic strain and fracture localization in a material with a bilayer coating

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A mesomechanical analysis of plastic strain and fracture localization in a material with a bilayer coating

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Abstract. The deformation and fracture of a coated material with an interlayer is investigated. A dynamic boundary-value problem in a plane strain formulation is solved numerically by the finite-difference method. The mechanical responses of a steel substrate, interlayer material and iron-boride coating is simulated by means of an isotropic strain-hardening model and a fracture criterion taking into account crack initiation and growth in regions experiencing tensile stresses. Numerical experiments on tension and compression of two- and three-phase microstructures were conducted. The average mechanical properties of the interlayer material are considered. The coating-interlayer and interlayer-substrate interface geometries correspond to configurations found experimentally and are accounted for explicitly in the calculations. Local regions of bulk tension are shown to form near the interfaces even under simple uniaxial compression of coated materials, which controls the fracture mechanisms at the mesoscale level. The influence of the interlayer on macroscopic homogenized strength of coated materials and on localized plastic flow and cracking patterns is examined.

Keywords: Layered structures, Computational modelling, Stress concentrations, Plastic deformation, Fracture

1. Introduction

Interfaces are known to be responsible for stress concentration in local regions of loaded materials at different scale levels [1– 6]. The stress concentration, in turn, gives rise to plastic strain localization followed by fracture in plastically strained metals and to brittle cracking in ceramics, glass, etc. The main factors controlling the local stress level are the local curvature of interfaces and the difference in the mechanical properties of contacting materials. Thus, the presence of interfaces may produce a profound effect on the deformation and fracture response of materials under loading.

A prominent example of the case at hand is coated materials. The main feature of these materials is the presence of a coating-substrate interface, which may influence their mechanical properties. The behavior of the materials becomes even more complicated and difficult to predict in multilayer coatings. A great body of information on interfacial problems in mechanics (see, e.g., [6–13]) is devoted to interfacial fracture, delamination failure, decohesion and debonding under different types of loading, including shock waves. Numerical elastic-plastic and analytical elastic models [14–33] are mostly restricted to an idealized representation of interfacial geometry. In [14–29] a coated material is represented as a two-phase structure with a plane coating-substrate interface. An interface in the form of a regular wave is discussed in [30–33]. While the phenomena related to the irregular interfacial geometry are of great importance, a comprehensive study on the subject is yet to be performed.

Diffusion borating is a coating deposition technology that allows high-strength coatings with a toothed needle-like coating-substrate interface to be produced. Experimental evidence shows that depending on the type of steel used as a substrate material, different interfacial geometries can be obtained, including an interlayer between a high-strength austenitic steel substrate and a boron coating. The interlayer possesses different mechanical properties and has different configurations depending on the coating deposition regime and type of steel. An example is a 15H3MA steel substrate-interlayer interface characterized by a complex serrated profile. The latter is smoother than the profile of the coating-interlayer interface, but their geometry marked by a quasi-periodic alternation of interlayer teeth grown into the steel material is similar (Fig.1). At first glance, the interlayer serving as a damping layer between the coating and the substrate appears to play a positive role, decreasing the stress

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