

The Mechanics and Reliability of Films, Multilayers and Coatings

A wide variety of applications ranging from microelectronics to turbines for propulsion and power generation rely on films, coatings and multilayers to improve performance. As such, the ability to predict coating failure – such as delamination (debonding), mud-cracking, blistering, crack kinking and the like – is critical to component design and development. This work compiles and organizes decades of research that established the theoretical foundation for predicting such failure mechanisms and clearly outlines the methodology needed to predict performance. Detailed coverage of cracking in multilayers is provided with an emphasis on the role of differences in thermoelastic properties between the layers. The comprehensive theoretical foundation of the book is complemented by easy-to-use analysis codes designed to empower novices with the tools needed to simulate cracking; these codes enable not only precise quantitative reproduction of results presented graphically in the literature, but also the generation of new results for more complex multilayered systems.

Professor Matthew R. Begley is broadly recognized for seminal contributions in the mechanics of multilayered systems with an emphasis on computational aspects of the required analysis. His codes are employed in some industries to design experiments, assess current designs and evaluate novel multilayer systems for improved performance. Both authors are widely sought after for consulting work on the mechanics of thin films, coatings and multilayers by companies such as General Electric, Pratt & Whitney, Intel, Sunpower, Raytheon, Areva etc.

Professor John W. Hutchinson is a member of the US National Academies of Engineering and Sciences and a Foreign Member of the Royal Society of London. He is one of the leading experts in the mechanics of thin film systems, with a number of highly cited, seminal journal papers on the subject. Hutchinson is broadly credited with generating many of the conceptual developments in this field, as well as illustrations of those concepts to applications ranging from microelectronics to thermal barrier coatings, microfluidic devices, hypersonics etc.

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Notation

The list below refers to the most common usage:

| | |
|-----------------------------------|--|
| $\Lambda_U, \Lambda_B, \Lambda_o$ | strain energy per unit area in thin strips |
| α | coefficient of thermal expansion |
| $\epsilon_{ij}, \sigma_{ij}$ | strain and stress tensors, respectively |
| E, ν | elastic modulus and Poisson's ratio |
| $\bar{E} = E/(1 - \nu^2)$ | plane strain modulus |
| E_* | effective interface modulus, eqn. (3.14) |
| $\eta_x, \eta_y, \eta_{xy}$ | large strain definitions |
| α_D | first Dundurs' parameter, eqn. (3.9) |
| β_D | second Dundurs' parameter, eqn. (3.9) |
| ϵ | mismatch parameter when $\beta_D \neq 0$ |
| θ | stress-free misfit strain, such as thermal expansion |
| \bar{c} | coefficient of misfit strain defined by geometry constraint |
| $u(x), w(x)$ | axial and transverse displacements, respectively |
| κ | curvature (second derivative of transverse displacement) |
| ϵ_o | axial stretch of the reference axis |
| σ_o, σ_c | residual stress and critical stress for buckling |
| N, M | axial force and bending moment resultants, respectively |
| a_{ij}, b_j | coefficients in multilayer equations to find ϵ_o and κ |
| G | energy release rate |
| K_I, K_{II} | isotropic stress intensity factors |
| K_1, K_2 | interface stress intensity factors |
| Γ_I, Γ_{II} | interface toughness in mode I and mode II |
| η | dimensionless stress parameter for kinking/deflection |
| λ | fitting parameter that dictates mode II toughness |
| ψ | phase angle that defines mode-mix |
| ω | phase factor used to compute mode-mix |
| ΔT | temperature change from stress-free reference state |
| q | heat flux |
| k | thermal conductivity |