Stress concentration in ultra-thin film coating with undulated surface profile

Sergey A. Kostyrko*, **Holm Altenbach**† **and Mikhail A. Grekov***

* Department of Computational Methods in Continuum Mechanics,
St. Petersburg State University,
7/9 Universitetskaya nab., St. Petersburg, 199034, Russia,
e-mail: {s.kostyrko, m.grekov}@spbu.ru, web page: http://www.spbu.ru/

†Institute of Mechanics,
Otto von Guericke University,
Universitätsplatz 2, Magdeburg, 39106, Germany,
e-mail: holm.altenbach@ovgu.de, web page: http://www.ovgu.de

ABSTRACT

Thin films materials with a layer thickness from hundreds to a few nanometers exhibit unique physical and mechanical properties that can't be observed in bulk materials. Improved material properties are referred to significant modifications in the structure during an atomic growth process and so-called size effect related to surface stresses [1, 2]. At the stage of film deposition and subsequent thermal processing, the film surface evolves into an undulating profile. Misfit stresses enhanced by a curved surface generate severe stress concentrations which may lead to nucleation of dislocations and microcracks. Analyzing a regular surface patterns in mono- and multilayer film coatings, it was found that even a slight undulation in surface morphology can result in a substantial increase of hoop stresses near the bottom of cavities [3]. It has been shown that the stress concentration factor depends on the curvature radius and depth of cavities as well as the thickness and stiffness of film layers. However, the effect of surface elasticity on a stress state of thin film was neglected in comparison with the effect of macroscopic bulk elastic behavior.

In the presenting research, an extended continuum model of coherently strained thin film with a nanoscale thickness deposited on a thick substrate is proposed by incorporating the coupled effect of surface and interface stresses. Generally, the uniaxial loading of an isotropic film-substrate system with a sinusoidal surface profile and planar interface is considered under plain strain conditions. We formulate the corresponding boundary value problem involving two-dimensional constitutive equations for bulk materials and one-dimensional equations for membrane-type surface [1] and interface [2] with an extra elastic constants as well as residual surface stresses. Mixed boundary conditions consist of generalized Young-Laplace equations and relations describing the continuous of displacements across the surface and interphase regions. Using the linear perturbation technique combined with Goursat-Kolosov complex potentials and the superposition principle, the original boundary value problem is reduced to the analytical solution of the integral equations system.

REFERENCES

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