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Internal stress analysis for single and multilayered coating systems using the boundary element method

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ABSTRACT

Various thin-coating films are designed and utilized for industrial applications to improve machining performance due to better temperature and wear resistant properties than their substrate counterparts. However, the widespread experimental research on thin coatings underlies a general lack of modeling efforts, which can accurately and efficiently predict the coating and thin film performance. In this paper, the boundary element method (BEM) for 2D elastostatic problems is studied for the analysis of single and multilayered coating systems. The nearly singular integrals, which is the primary obstacle associated with the BEM formulations, are dealt efficiently by using a general nonlinear transformation technique. For the test problems studied, very promising results are obtained when the thickness of coated layers is in the orders of 1.0E−6 to 1.0E−9, which is sufficient for modeling most coated systems in the micro- or nano-scales.

1. Introduction

In industrial applications, more and more new materials have been synthesized, characterized and put into use in recent years. Among these materials, the structures containing thin coated layers deserve special mention. Thin layers of coating protect the material against corrosion, fatigue and intensive abrasive wear, and therefore the surface-coated materials perform more efficiently even under some extreme working conditions. To improve coating performances, multilayered systems, which are the so-called third generation coating systems [1] containing multiple layers of thickness in the micrometer and nanometer range, are created to overcome the optical, mechanical and/or barrier property limitations of single-layered coatings [2,3]. In engineering practice, robust models for coating performance are crucial for accurate design and analysis of systems containing such thin structures. However, the widespread experimental research on thin coatings underlies a general lack of modeling efforts, which can accurately and efficiently predict the coating and thin film performance, including interfacial stresses and fatigue life [4,5].

It is well known that the numerical analysis for coating systems has been performed by utilizing experimental, analytical and numerical methods. The usual numerical methods such as the finite element method (FEM) and the boundary element method (BEM) can be applied to solve such problem. FEM is a successful tool for the analysis of many industrial problems. However, the aspect ratio issues associated with the FEM when applied to thin structures limit its application. To maintain element aspect ratio, a large number of elements must be discretized, and the procedure therefore requires much preprocessing and CPU time as the thickness decreases. The BEM is a powerful and efficient computational method if boundary integrals can be evaluated accurately. The main advantage of the BEM resulting from the reduction in the dimension of the boundary value problem is well known. However, it is popular as well that the standard BEM formulations include singular and nearly singular integrals, and thus the integrations should be performed very carefully. Some of the recent applications of the FEM for thin films or coatings can be found in Refs. [6–13]. All these FEM studies show that very fine finite element mesh is essential in order to accurately evaluate the interfacial/internal stresses in thin films and coatings. On the other hand, there are very few studies, reported recently, using the BEM for the analysis of thin films and coatings, especially for multilayered coating systems. In Ref. [14], the BEM based on an approximate Green's function is developed and applied successfully to the problem of electromigration-driven void dynamics in metallic thin film interconnects. In Ref. [15], a multi-domain approach is proposed to determine the temperature fields in materials containing thin coatings. However, this method is inefficient when the coating is very thin due to the lack of efficient techniques to calculate the nearly singular integrals. Liu et al. has undertaken great amount

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