Engineering Structures 33 (2011) 3269–3278

Contents lists available at SciVerse ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

A computational and experimental investigation of three-dimensional micro-wedge indentation-induced interfacial delamination in a soft-film-on-hard-substrate system

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ARTICLE INFO

Article history:
Received 5 November 2010
Received in revised form
14 May 2011
Accepted 19 August 2011
Available online 29 September 2011

Keywords:
Three-dimensional finite-element (FE) simulation
Interfacial delamination
Soft-film-on-hard-substrate (SFHS)
Traction–separation law
Micro-wedge indentation

ABSTRACT

A three-dimensional finite element (FEM) simulation was performed to study the mechanics of micro-wedge indentation-induced interfacial delamination of a soft film from a hard substrate. In this simulation, a traction–separation law, with two major parameters: interfacial strength and interfacial energy, was used to characterize the failure behaviors of the interface. Cracking of film and residual stresses were not included. The initiation and growth of the interfacial delamination were investigated for a wide range of interfacial properties. It was found that the interfacial strength influences the initiation of delamination more than does interfacial energy, while the interfacial energy is more effective to affect the propagation of the delamination crack. The effects of the length of wedge indenter tip and the thickness of film on the onset and growth of interfacial delamination were also analyzed. Furthermore, the interfacial delamination process by micro-wedge indentation was conducted experimentally, and the delamination crack fronts as well as the P–h curves in experiments and computations were compared thoroughly. Comparisons between the computational and experimental results yield quantitative good agreement.

1. Introduction

In recent years, the deposition of films has been extensively employed to protect the underlying ductile substrate material against wear, damage and thermal degradation [1]. Therefore, thin film systems are widely used in many technologically important application areas, including microelectronics and optoelectronics devices, magnetic data storage, medical devices, and many more [2]. However, the use of these films to enhance the performance of engineering components is usually accompanied by the risk of their failure due to brittle fracture in response to mechanical loads [3]. An important issue in all of the thin-film/substrate systems is the adhesion of the interface between the film and substrate, since the interfacial delamination may lead to a system failure even though the film and substrate still satisfy the technical requirements [4]. Hence, it is imperative to understand this behavior of thin-film systems in order to improve their design and ensure the integrity of the film during service [5].

For ultra-thin films, the thickness of the films is usually of the order of few hundred nanometers. Therefore, their interface adhesion properties are difficult to measure using conventional mechanical testing techniques [6,7], such as tensile and bending tests. On the other hand, micro-indentation techniques [8,9], such as spherical [10], conical [11–13], and wedge [14–16] indentation experiments, have been proven very effective in the investigation of interfacial delamination of film systems [17]. During the nanoindentation tests, the interfacial delamination can be reflected and identified by characteristic changes in the indentation load–displacement curves (P–h curves). For example, Swain and Mencik [10] demonstrated various responses in the indentation load–displacement curves caused by interfacial delamination during spherical indentations. Later on, Drory and Hutchinson [18] developed the conical indentation analysis to assess the interface toughness. Furthermore, the wedge indentation method has been developed [15,16,19]. Recently, Yeap et al. [20,21] adopted the wedge indentation method and focused-ion-beam (FIB) technique to determine the interfacial toughness

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doi:10.1016/j.engstruct.2011.08.028