Acta Biomaterialia 8 (2012) 1469–1480

Contents lists available at SciVerse ScienceDirect

Acta Biomaterialia

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

Adhesion and cohesion in structures containing suspended microscopic polymeric films

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ARTICLE INFO

Article history:
Received 20 August 2011
Received in revised form 6 December 2011
Accepted 12 December 2011
Available online 16 December 2011

Keywords:
Adhesive strength
Cohesive strength
Suspended microscopic polymeric films
Finite element modeling
Stents

ABSTRACT

This paper presents a novel technique for the characterization of adhesion and cohesion in suspended micro-scale polymeric films. The technique involves push-out testing with probes that are fabricated using focused ion beam techniques. The underlying stresses associated with different probe tip sizes were computed using a finite element model. The critical force for failure of the film substrate interface is used to evaluate adhesion, while the critical force for penetration of the film determines cohesion. When testing a standard material, polycarbonate, a shear strength of approximately 70 MPa was calculated using the Mohr–Coulomb theory. This value was shown to be in agreement with the results in the literature. The technique was also applied to the measurement of adhesion and cohesion in a model drug-eluting stent (the Nevo™ Sirolimus Eluting Coronary Stent) containing suspended microscopic polymeric films in metallic Co–Cr alloy reservoirs. The cohesive strength of the formulation was found to be comparable with that of plastics such as those produced by reaction injection molding and high-density polyethylene.

1. Introduction

In the rapidly expanding fields of medical devices and microelectronics thin polymeric films have enhanced the properties of the systems they coat [1]. For example, the results obtained from prior work suggest that in cases where formulations of drugs and polymers have been applied to stents the resulting drug-eluting stents result in reduced restenosis, the re-narrowing of treated arteries, over their metallic counterparts [1]. The adhesion of such films to their substrates has been the subject of several studies [2–9].

Nano-mechanical tests have been developed to gain an insight into the adhesion and the fundamental mechanical properties of thin films [2–6]. In these tests a stylus first comes into contact with a sample, which is then indented to shallow nano-scale depths. In the nanoindentation test a normal force is applied to the tip and its displacement is recorded [2]. A stress is induced in the film surrounding the indenter that can initiate and propagate interfacial cracks.

Single/multiple indents (as in ISO method 14577) have also been used to measure hardness, the Young's modulus, and interfacial fracture toughness of thin films, thick coatings and bulk materials [3–6]. The indentation interfacial toughness, a direct measure of adhesion, can be estimated by analyzing the indented area. For example, a nanoindentation method was used to evaluate the adhesion strength of poly(N-isopropylacrylamide) co-polymers on nitinol wires [5]. The interfacial fracture toughness G varied from 0.1 to 0.3 J m^{-2}, depending on the surface roughness of the film.

The nanoscratch test consists of application of vertical and lateral forces to the tip [3,4]. Using either constant or progressive forces the critical load that provokes coating detachment can be measured. This measurement is then used to evaluate scratch hardness and scratch adhesion of the thin films. For example, to evaluate the relative adhesion of the coatings of three commercial drug-eluting stents to their corresponding substrates the forces to induce delamination between the coating and the stent were measured by a nanoscratch method and were found to be comparable [6].

In previous works [7–9] we have used a combination of models and experiments to study the adhesion between soft films and hard substrates. Atomic force microscopy (AFM) [7] and interfacial fracture mechanics techniques [8,9] were used to measure the adhesion between different interfaces within and between the coated substrates. A combination of adhesion theory and interfacial fracture mechanics models was then used to obtain adhesion

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doi:10.1016/j.actbio.2011.12.018