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Sub-surface fracture of a thin metallic foil under impact loading

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ABSTRACT

We examine here sub-surface fracture of a thin metallic foil sandwiched between two elastomeric layers under impact. In particular we generate a vertical stack consisting of alternate layers of soft elastomers and thin aluminum foils and place it on a rigid substrate; we then allow a rigid sphere to impact the stack from a small vertical height. We show that under impact the foil at the top of the stack undergoes buckling deformation; however the foil sandwiched between the two elastic layers undergoes both deformation and fracture. We show that because of friction at the contacting interfaces with the elastomer, the sandwiched foil is subjected to in-plane stretching which when exceeds a threshold limit causes fracture. Experiments show that this threshold condition is reached within a range of critical thicknesses of the top and bottom elastomeric layers, for a given height of impact of the rigid spherical indenter. We present a theoretical analysis to predict the critical thickness of the stack below which the foil is expected to undergo fracture and also the critical heights within this stack at which the foil would fracture.

1. Introduction

Impact of a rigid object onto a soft elastic and visco-elastic solid causes surface indentation, large deformation, viscous flow, dissipation of heat and even fracture and permanent damage. While these processes occur at the surface of the material and remain visible and tractable, in many situations, specially for low intensity impact, apparently no damage occurs at the surface of the layer although a substrate underneath it undergoes considerable damage. A common example is the impact of human body with rigid or deformable objects: very often, the outer surface of the skin does not show any sign of damage but substantial fracture occurs in the muscles, blood vessels and even in bones that lie beneath the outer skin (Buckwalter, 2002). Sometimes such fracture is minimal initially but resurfaces years later to cause major health problems. It is not uncommon that forensic scientists have to often grapple with fatalities caused by sub-surface fracture arising out of accidents or homicide. Sub-surface fracture is important also for variety of engineering applications. For example, under low-intensity impact, fracture initiates in composites (Abrate, 1997; Anderson and Madenci, 2000; Gent and Lindley, 1959) not at the surface but at a sub-surface location, detection of which poses an important engineering challenge. In paints and coatings (Suo and Hutchinson, 1990; Hutchinson and Evans, 2000; Chai, 2009) too peeling off a buried layer occurs much ahead of an eventual failure at the surface of the coating. Subsurface fracture is important also for applications involving flexible electronics (Lacour et al., 2006; Jiang et al., 2007; Li et al., 2004; Wang et al., 2008; Khang et al., 2006), e.g. skin sensors, flexible displays, artificial muscles, high precision metrology applications (Chung et al., 2010) and so on. These applications consist of thin metallic wires and interconnectors deposited on a soft, stretchable elastomeric substrate and many often deposited in multiple layers. Protection of these layered structures, specially the stiff metallic films, against variety of adverse environmental conditions, e.g. heat, humidity, scratch, oxygen, vibration, shock, even impact and accidental drop is an issue. The protecting layer for these devices should not only ensure complete isolation from these environmental extremities, but also, meet this requirement under the constraint that the overall flexibility of the device is not compromised. In fact it is somewhat intriguing that a device may seem well encapsulated by a protecting barrier, yet it gets damaged when subjected to a slightest perturbation, e.g. a low intensity impact. What causes sub-surface fracture is not very clear. In fact, there has not been much study particularly focused on fracture of a thin stiff film sandwiched between two other soft, deformable layers. For example, it is not known, when impacted, in what mode a sub-surface film fails, the threshold intensity of the impact at which such fracture initiates, the effect of material and geometric properties of the layers, the role of interfacial adhesion and friction and so on. In fact it is not known also how the material would behave when subjected to a repetitive load (Clements et al., 2001) or for example combination of a number of environmental adversities.

2. Experimental

It is in this context that we present here a low intensity impact experiment in which we place on a rigid substrate a vertical stack consisting of alternate layers of a soft elastomer and a thin metallic

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