Small-scale thin film experiments provide models for large-scale engineering applications

PROBLEM

Thin films are omnipresent in daily life as mirrors and other optical coatings, rolls of adhesive tape and microstructures for semiconductors. They're also critical for many civil and environmental engineering applications. Paint on steel, concrete shells on domed buildings, fiberglass-polymer wrapping on concrete bridges, seals for toxic waste and solar voltaic films on roofs all have geometric properties similar to thin films: a thin coating covering a large area. And all are prone to delamination, blistering, folding or cracking. In effect, thin films present enormous difficulties because of their propensity to resist deformation when the substrate expands or contracts.

APPROACH

MIT researcher Pedro Reis studies the fundamentals of thin film behavior at the laboratory scale by treating the thin films and substrates as nonlinear systems prone to fracture or delamination. To create these behavioral models of large-scale thin-film applications, Reis scales them down to well-controlled desktop-sized experiments that preserve the behavior of the larger systems. He achieves this by identifying invariants based on geometry and fracture or delamination properties. He has applied this research method to three notable thin film-substrate systems: the tearing of thin films as a fracture-adhesion process; the delamination mechanics of thin films; and localization in thin film-substrate interactions.

FINDINGS

Reis and collaborators studied the fracture-adhesion process in the triangle-shaped tears in thin films, a common and robust phenomenon that appears in everyday objects such as
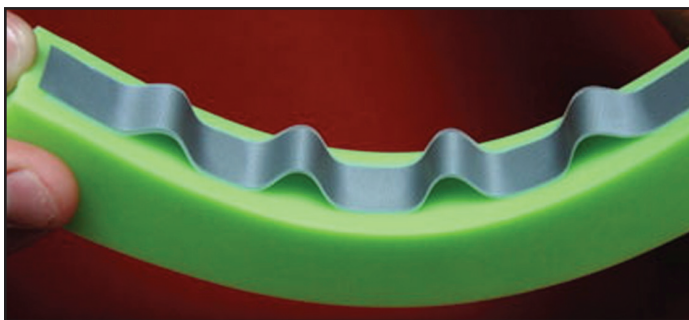
strips of wallpaper, tape pulled from a substrate, and tomato and grape peelings. They found that the triangular tears arise from the interaction among three properties: elasticity, adhesive energy and fracture energy. Knowing the tearing angle and two of these parameters makes it possible to predict the third.

Reis and colleagues also investigated delamination mechanics using controlled desktop experiments of adhesive sheets on top of an elastomer substrate. When the ensemble is compressed, the tape delaminates. The geometrical properties of the resulting blisters (amplitude, width and spacing) can be predicted if the thickness of the film, stiffness of the film and substrate, adhesion strength and amount of compression are known.

The third system models a system with a more complicated substrate — a thin polymer film permanently affixed to the top of a cellular solid foam — to study when, how and where localized deformation occurs under compressive loading. Initially, localized folds appear at the surface due to instability in the thin film at a scale set by the mechanical and geometrical properties of the system. This triggers a chain of collapse that gradually propagates through the foam substrate as planes of cells are progressively crushed, forming what Reis refers to as an anti-crack: a region of localization of deformation under compression. Eventually this band of collapse crosses the entirety of the sample. This process of localization is ubiquitous to a wide range of heterogeneous solids including porous rocks, polymer foams and soils.

Delamination occurs in a thin film adhered to a substrate when the substrate is compressed. The geometric properties of the resulting blisters occur in a predictable manner. Photo / Donna Coveney, MIT

IMPACT

An important common ingredient in thin film problems is the prominent role of geometry in the films' deformation. Reis' innovative experimental modeling approach makes it possible to identify physical relationships in the laboratory in a predictive way, and allows for the mechanisms to be scaled up or down to the scale of the particular application being studied — whether it be a nanoscale, microscale or very large-scale engineering project.

MORE

Reis, an instructor in mathematics at MIT, will join the faculties of the Departments of Civil and Environmental Engineering and Mechanical Engineering in July. The work referred to above appeared in Nature Materials (May 2008), PNAS (July 2009) and Physical Review Letters (July 2009).