QUANTITATIVE MEASUREMENT OF STRESS VS. STRAIN IN SUPPORTED THIN FILMS BY THE LAYER COMPRESSION TEST

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Nanoindentation is currently the only way to test local mechanical properties of supported thin films and coatings. However, current analysis treats the system as a perturbation of half-space indentation and struggles to adequately remove the response of the substrate and isolate the properties of the film. In the layer compression test (LCT), a flat punch with diameter much larger than the film thickness is aligned to the surface of a film on a stiff supporting substrate. This test condition generates uniform uniaxial strain throughout a compressed puck of material to a high degree of inelastic strain during indentation. This allows for mechanical analysis of intrinsic thin film stress vs. strain in both elastic and plastic regimes of deformation (Fig. 1d), including simultaneous numerical characterization of elastic modulus, Poisson's ratio and the point of a sharply defined yield transition. In this work[1], we present finite element analysis of the layer compression test to assess its fidelity to producing uniaxial strain in a range of contact aspect ratios and substrate to film moduli ratios for an E/Y ratio of 10 typical of amorphous systems such as polymers and biofilms. We present also experimental results for LCT indention of a film of polystyrene supported on a silicon substrate with contact aspect ratio ranging from 9 to 22 in order to verify the trends and results apparent in the simulation.

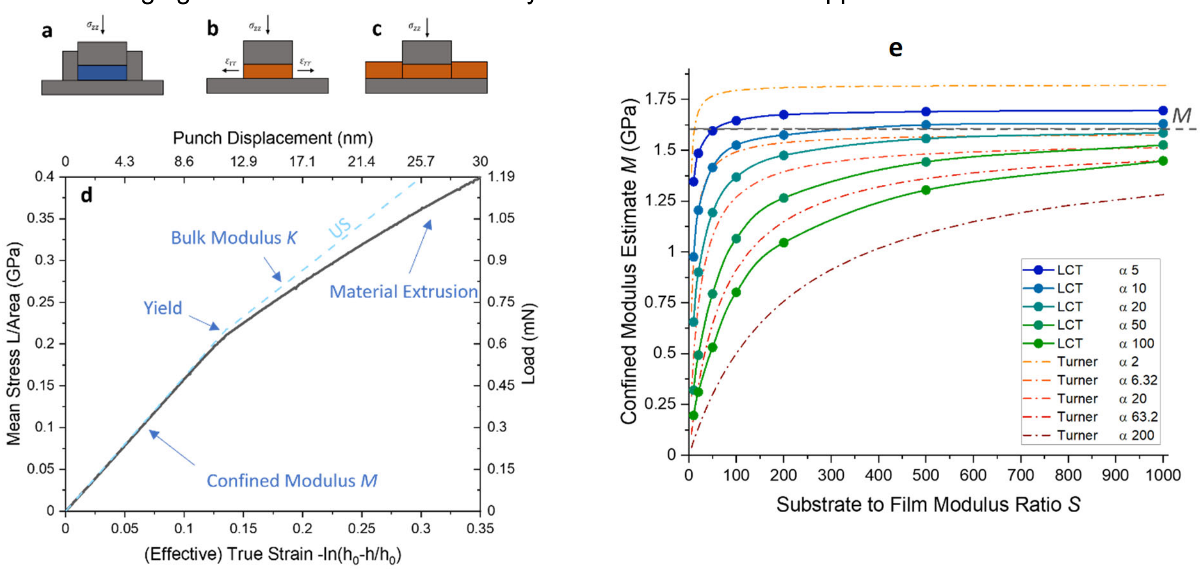

Fig 1. Representation of (a) true uniaxial strain, (b) unconfined uniaxial stress, and (c) layer compression test approximation of uniaxial strain. (d) shows stress-strain relation for a typical LCT indent (black line, aspect ratio 20, E_{film} = 1 GPa, E_{sub} = 500 GPa) compared to pure uniaxial strain (dotted blue line), demonstrating values that can be extracted from such an indent such as the confined modulus M, bulk modulus K, and yield point. (e) Compiled values of confined modulus for LCT indentation for a range of contact aspect ratios α and substrate to film modulus ratios S, compared to previous zero-strain analytical estimates by Wald et al[2] and true confined modulus M. A simple analytical substrate correction step can correct for much of the error inherent for lower S ratios

1. Aaron D. Sinnott, Owen Brazil, Graham L. W. Cross, The effect of contact aspect ratio and film to substrate elastic modulus ratio on the uniaxial strain state approximation to flat punch thin film indentation in the elastic regime, submitted to Frontiers in Materials, 2022
2. Wald, M.J., J.M. Considine, and K.T. Turner, Determining the Elastic Modulus of Compliant Thin Films Supported on Substrates from Flat Punch Indentation Measurements. Experimental Mechanics, 2013. **53**(6): p. 931-941.