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Stress in thin films: Transition from spherical to cylindrical deformation

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Abstract – The deformation of samples assembled as a thin film on thick substrate is evaluated by means of the minimization of the deformation energy of the samples, considering the compressibility character of the material given by the Poisson ratios. This approach is considered for the analysis of the deformation process, that indicates a transition from spherical to cylindrical shape and is applied to a cylindrical sample obtaining a correction term to Stoney equation.

This work has been motivated by the need of understanding stress distribution in thin films on thick substrates [1] and of obtaining more accurate equations to calculate it, out of the validity limits of the well-established Stoney equation [2].

$$\sigma = \frac{E_s \cdot t_s^2}{6 \cdot (1-\nu_s) \cdot t_f} K \qquad (1)$$

where σ is the film stress, E_s is the substrate Young modulus, t_s e t_f are the substrate and film thickness and K is the film curvature. In fact, Finot et al [3] using a finite element analysis identified three distinct regimes for the evolution of curvature K, in such a way that for lower values of K, the deformation has a spherical shape and Stoney equation is satisfied; (II) as K increases, deformation maintains the spherical shape but Stoney equation looses validity and (III) for even larger values of K, Stoney equation is no longer valid and the sample undergoes two abrupt changes, initially to an ellipsoidal shape and finally to a cylindrical shape.

In our previous work [4], it is proposed a first principles approach to study deformation of samples assembled as a thin film on thick substrate. The approach is the minimization of the deformation energy of the sample (substrate + film) and considers the compressibility character of the material given by the substrate Poisson ratio ν_s. For a substrate deformed as a small spherical surface with large curvature radius (regime II) the results are comparable with Finot values, indicating that the stress values obtained by Stoney equation and others results in the literature [5] were underestimated when considering a typical Poisson ratio for substrates in the range of $0.25 \leq \nu_s \leq 0.4$.

In this work, we applied the same approach a substrate with a cylindrical deformation, taking into account hard materials with high intrinsic stress when spherical deformation can no longer be considered (regime III) [2], and the results show a correction term for Stoney equation. Moreover, we analyze the deformation process along the three regimes, relating the changes of the shape of the sample to the minimization of the deformation energy.

References

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