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Closed-form solutions for bonded elasticallycompressible layers

Lu, Nanshu, lunanshu@gmail.com, University of Texas at Austin

ABSTRACT

Compression of elastic layers between parallel plates often finds applications in the mechanical characterization of soft materials or the transfer-printing of nanomembranes with rubber stamps. In addition, annular rubbery gaskets and sealers are often under uniaxial compression during service. Analysis of elastic layers under compression has been focused on incompressible materials, and empirical assumptions of displacements were adopted for simplicity. For compressible materials, solutions obtained by the method of averaged equilibrium are sufficient for effective compression modulus but inaccurate for the displacement or stress fields, whereas solutions obtained by the method of series expansion are considerably complicated. In this article, we report full field, closed-form solutions for bonded elastic layers (disks, annuli, annuli with rigid shafts, infinitely long strips) in compression using separation of variables without any preassumed deformation profile. Our solutions can satisfy the exact forms of the equilibrium equations and all the essential boundary conditions as well as the weak form of the natural boundary conditions. Therefore, the predicted stress, displacement, and effective modulus have found excellent agreement with finite element modeling (FEM) results over a wide range of Poisson's ratio and aspect ratio. Our analytical and FEM solutions of the stress, displacement, and effective modulus are highly sensitive to Poisson's ratio, especially near 0.5. Therefore, we also propose a viable means to simultaneously measure the intrinsic Young's modulus and Poisson's ratio of elastically compressible layers without camera settings. When Poisson's ratio approaches 0.5, our solutions can degenerate to classical solutions for incompressible elastic layers.