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CAVITATION IN ELASTOMERIC SOLIDS: A DEFECT-GROWTH THEORY

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Abstract. Physical evidence has shown that sufficiently large tensile loads can induce the sudden appearance of internal cavities in elastomeric solids. The occurrence of such instabilities, commonly referred to as cavitation, can be attributed to the growth of pre-existing defects into finite sizes. Because of its close connection with material failure initiation, the phenomenon of cavitation has received much attention from the materials and mechanics communities. Cavitation has also been a subject of interest in the mathematical community because its modeling has prompted the development of techniques to deal with a broad class of non-convex variational problems. While in recent years considerable progress has been made via energy minimization methods to establish existence results, fundamental problems regarding the quantitative prediction of the occurrence of cavitation in real elastomeric materials remain largely unresolved.

In this work we present a new theory of cavitation in elastomeric solids that simultaneously (i) allows to consider general 3D loading conditions with arbitrary triaxiality, (ii) applies to large (including compressible and anisotropic) classes of nonlinear elastic solids, and (iii) incorporates direct information on the initial shape, spatial distribution, and mechanical properties of the underlying defects at which cavitation can initiate. The basic idea is to first cast cavitation in elastomeric solids as the homogenization problem of nonlinear elastic materials containing random distributions of zero-volume cavities (i.e., the defects). The problem is then solved for a particular class of microgeometries by means of a novel iterated homogenization procedure. The solutions contain information on the change in size of the underlying cavities as a function of the applied loading conditions, from which the onset of cavitation --- corresponding to the event when the initially infinitesimal cavities suddenly grow into finite sizes --- can be determined.

In spite of its generality, the proposed approach requires the solution of tractable Hamilton-Jacobi equations, in which the initial size of the cavities plays the role of “time” and the applied load plays the role of “space”. Sample results will be presented for the onset of cavitation in Neo-Hookean solids subjected to arbitrary 3D loading conditions. In this connection, it should be emphasized that the vast majority of cavitation studies to date have been almost exclusively limited to hydrostatic loading conditions, presumably because of the simpler tractability of this relevant but overly restricted case. However, we find that the occurrence of cavitation depends strongly on stress triaxiality.