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Non-linear frictional contact mechanics of visco-hyperelastic materials

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Contact mechanics represents a topic of primary importance in mechanical engineering and tribology, with direct implications for the design and analysis of critical components in several application fields, including aerospace, automotive, and biomedical engineering. The increasing use of soft materials, such as those employed in sealing systems, tires, and soft robotics devices, leads to operating conditions characterized by large deformations and displacements, which cannot be adequately described within the framework of linear elasticity. In this context, the presence of friction and the viscoelastic behavior of the material contribute to making the contact mechanical response significantly more complex.
The present study addresses the contact problem in soft materials within a theoretical and numerical framework capable of capturing its strongly nonlinear and dissipative nature. Particular attention is devoted to the combined effects of interfacial friction conditions, large deformations, and viscoelastic material behavior, investigated through a finite element model developed to assess the contribution of the main parameters governing the system response. In particular, the contact between a rigid sphere and a soft visco-hyperelastic substrate is considered.
A relevant result is the emergence, during a loading-unloading cycle, of a non-adhesive pull-off force. This phenomenon is attributed to the combined action of friction, viscoelasticity, and geometric nonlinearities, and is found to strongly depend on the loading rate and on the material properties. The study further shows that the contact problem is intrinsically time- and path-dependent, and that friction contributes significantly to hysteretic losses, which are further amplified by geometric and constitutive nonlinear effects.

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