Elasto-plastic–damage variational formulation for strain gradient solids and pantographic interactions

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Abstract: This work is devoted to the presentation of a continuum theory for materials having granular microstructure and accounting for tension–compression asymmetry of eventually pantographic grain interactions and for dissipative phenomena like damage and plasticity. The continuum description is constructed by assuming expressions of elastic and dissipation energies as well as postulating a hemi-variational principle, without incorporating any additional postulates like flow rules. Granular micromechanics is connected kinematically to the continuum scale through Piola's ansatz. Mechanically meaningful objective kinematic descriptors aimed at accounting for grain–grain relative displacements in finite deformations are proposed. Karush–Kuhn–Tucker (KKT)-type conditions, providing evolution equations for damage and plastic variables associated with grain–grain interactions, are derived solely from the fundamental postulates. Numerical experiments have been performed to investigate the applicability of the model. Results show interesting damage and plastic induced anisotropy evolution including the emergence of a type of chiral behavior and formation of finite localization zones. Besides, loading–unloading histories have been considered to elucidate the material hysteretic features of the continuum. We also assess the competition between damage and plasticity, each having an effect on the other. Further, the evolution of the load-free shape is shown not only to assess the plastic behavior, but also to make tangible the point that, in the proposed approach, plastic strain is found to be intrinsically compatible with the existence of a placement function.

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