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Design and optimization of shock absorbers made of graded density foams

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Polymer foams are widely used in cushioning applications, such as helmet liners, due to their high energy absorption capabilities during plastic deformation. At the cellular level, deformation occurs through mechanisms such as bending, stretching, buckling, and tearing of cell walls, with wall thickness closely linked to foam density. By tailoring density variations, Functionally Graded Foam Materials (FGFM) can be designed to enhance impact energy dissipation.

This study focuses on the design and numerical evaluation of a FGFM energy absorber featuring a 2D density gradient. A visco-elasto-plastic material model for PVC foam was calibrated based on experimental tests conducted at different densities (130, 200, and 250 kg/m^3) and strain rates (10^{-3}, 10^{-1}, 10^1, and 10^3 s^{-1}). The material response was characterized using the Ogden hyperelastic model, Prony series for viscoelasticity, and the Mullins effect to account damage accumulation. The model was implemented in Abaqus/Explicit via a VUMAT subroutine, allowing for accurate simulation of foam behavior under dynamic loading.

The primary objective was to evaluate the benefits of density grading in energy absorption and identify optimal density distributions to minimize punch acceleration in a puncture test. Impact simulations demonstrated the potential of FGFM to improve energy dissipation efficiency, offering insights into the optimization of foam structures for protective applications.

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