OPTIMAL DESIGN OF MULTI-LAYERED CELLULAR SYSTEMS FOR PULSE LOADING

By

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Abstract

Two methods and physical models are presented to solve the nonlinear wave equation with shock formation using mass, momentum, and energy conservation in a multi-layer one-dimensional rods made of cellular material. Using the method of characteristics, the rigid-perfectly-plastic-locking model is proven to be unable to predict shock formation at a material interface. Thus, a rate-independent mechanical model is proposed and incorporates an elastic-plastic-densifying material model to describe the stress-strain behavior of the cellular materials is proposed. The conditions for shock formation at a material interface are provided. A two-layer analysis is conducted to gain insights into the behavior of two layer cellular systems and to determine which material properties are most important for design. Finally, the significant parameters are optimized to reduce the length of one and two layered cellular systems with impulse and mass constraints subject to pulse loading. The results reinforce the concept of sandwich structures and show that two layer systems can achieve a 30% reduction in length over single layer ones.

Next, a rate-dependent thermo-mechanical model is used to incorporate thermal and viscoplastic effects; the finite difference method is used to solve this model. Analysis of 1-layer systems reveals a viscoplastic stress spike on the distal boundary. Additionally, experimentally observed stress amplification is determined to be a function of the material velocity behind the incident shock in the layer. The amplification amount is derived analytically and matches well with existing models. Initial and boundary condition studies on the one-dimensional multi-layer cellular systems are conducted. The results indicate that pre-stressing and convex density arrangements reduce the peak impulses transferred through the system. Increasing temperature is found to increase system crush while reducing distal stress. Further, load pulse shape affects the shape of shocks and transmitted loads. Finally, increasing the number of layers in an even length distribution will reduce the performance of the material if the same linear density gradient is used. These results indicate a significant leap in the understanding of multi-layer cellular materials subject to pulse loads.