Modifying Automotive based Finite Element Models of the Lower Extremity with High Rate Heel Properties for simulating a Blast Loading Condition

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Abstract

Severe lower extremity injuries are a major concern for military personnel exposed to blast loading in armored vechicles. These injuries include foot, ankle, and lower leg fractues and account for more than 80% of all injuries observed in underbody blast (UBB) events. Battlefield epidemiology suggests that these injuries are caused by high-rate axial loading to the lower extremities from contact between the deforming vehicle floor and the occupant's feet. Thus, the soft tissue layer in the plantar region of the foot is the first structure engauged and may significantly influence mechanical response of the lower limb during UBB. Anthropometric test devices (ATDs) and finite element (FE) models are useful tools for studying lower limb mechanics during blast-type loading. However, these models lack accurate heel compression characteristics for high-rate loadings because they are only validated for rates corresponding to automotive impacts. In this study, high-rate mechanical properties for both post-mortem human surrogate (PMHS) and Hybrid-III (H-III) subcalcaneal heel pad were acquired and used to improve the fidelity of current FE models for high-rate loading applications.

Materials for this study were tested under uniaxial compression up to 60% strain. PMHS heel pads were collected from the hind foot region of four donors. Cylindrical tissue samples were cut from whole heel pads and then characterized through a battery of ramp and hold tests up to 30s-1. Cubic skin samples taken from the H-III dummy were characterized through impact testing using a drop tower which delivered impact velocities up to (2-3)m/s, 100s-1. An exponential hyperelastic model with time dependent material coefficients was used to fit the experimental data and numerical values for the model were determined using the least squares method. The response of the H-III heel pad was found to be much stiffer (4.4±0.1)MPa than that of the PMHS (12.6±3.7)kPa.

Fidelity of the lower leg FE models was evaluated using the H-III dummy (LSTC) and 50th percentile male (GHBMC). Both models were modified with high-rate constitutive properties determined for heel pad. The performance of the modified model was compared to the unmodified version using previously acquired data from drop tower tests performed on PMHS and H-III lower legs. For these tests, the proximal ends of 18 lower legs were mounted on a drop tower equipped with an impactor capable of producing axial loading on the foot up to 600g's over 1.5ms. Using the unmodified versions, the force time histories measured at the proximal end of the leg poorly represented the experimental data; the peak proximal tibia force in the FE models were approximately 50% larger, while the phase-delay and force pulse duration were nearly twice as long. The modified FE models elimanted discrepancies with force amplitudes and phasing. The force-time history for the modified H-III model was nearly identical to those measured in the experiment. The modified human model response had an average R^2=0.85 over the entire experimental force time-history. These results demonstrate that implementing high-rate material properties in FE models of the lower limb greatly improves model fidelity for high-rate loading conditions.