Computational Simulation of Shock Wave Propagation in Blast and the Effect of Shock Thickness on Resultant Stresses

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Abstract

Blast-induced neurotrauma (BINT) has been called the signature wound of war in the last decade; however, the mechanisms of BINT are not yet completely understood. Finite Element (FE) analysis has proven to be an indispensable tool in simulating material deformation under blast loadings. In this study, an FE model of three objects (human, porcine, and rodent head) under blast loading was developed to investigate the effect of shock front thickness and the geometry of the object exposed to blast on the resultant loading dynamics.

A Finite Element (FE) model was developed in LS-DYNA (LSTC, Livermore, CA) to simulate the detonation of high explosives (TNT and C-4), using the Arbitrary Lagrangian Eulerian (ALE) element formulation to simulate the flow of gases. Ideal gas and Jones-Wilkins-Lee (JWL) equations of state were used to simulate the air and the high explosives, respectively. A linear elastic material model was used to simulate the skull and the brain was modeled using a hyperviscoelastic formulation. Multi-Material ALE Group (MMAG) algorithm was utilized to capture the effect of air mixture with the gas generated by the explosive by interface reconstruction method. The Fluid-Solid Interaction (FSI) between the shock wave and the solid object was modeled using the constrained-solid method available in LS-DYNA.

The computational model was validated for 1 lb of TNT, against experimental data published in the literature for peak pressure versus stand-off distance to relative error of less than 5%. The correlation between the initial detonation velocity (explosive type) and mesh resolution on the shock front thickness was determined. Subsequently, two dimensional and geometrical indices were defined to characterize the effect of shock thickness (1-20 mm) on the object loading dynamics, i.e. pressure distribution and impulse. Due to the larger and more symmetrical geometry, the human head underwent much larger impulse per area (38%) given the same initial conditions. This can be particularly important to take into consideration when simulating blast conditions using shock tubes, which generate larger shock thicknesses (15-30 mm) as shown by experimental results.