Abstract

Traumatic Brain Injury (TBI) disrupts brain function due to head impacts, blast exposures, and ballistic penetrations. It is a significant cause of mental health issues and disability, particularly among military personnel. Historically, combat helmets were designed primarily to protect against fragments. However, recent data highlights the need for helmets that also provide protection against blast and blunt impacts. Effective TBI prevention requires helmets that address various energy threats while remaining lightweight. A critical metric in this effort is head acceleration, which is closely linked to injury across different scales of brain damage.

Four lattice structures were 3D printed using Digital ABS and composite digital materials and tested under static compression and low velocity impact (LVI). Static tests measured total strain energy, while LVI tests assessed impact resistance via the mitigation of acceleration and kinetic energy change. Stretching-dominated lattices absorbed more static energy but transmitted higher magnitude vibrations. A novel multilayer helmet design, incorporating carbon fiber, Kevlar, 3D printed lattices, and foam, outperformed the US Army Advanced Combat Helmet (ACH) in LVI tests, reducing acceleration by 40% and being 29% lighter. A theoretical model was developed and validated to predict the response of the multilayer composite structure. An explicit finite element method was used to optimize both bending and stretching-dominated cellular structures using five viscoelastic digital materials under three different impact loading scenarios. The goal was to minimize peak accelerations and mass through functional grading. Bending dominated structures made of soft materials are superior for impact resistance but come at the cost of higher mass. The results were evaluated against head injury criteria, highlighting the tradeoff between reducing acceleration while maintaining lightweight designs.