Development and Characterization of Microcellular Foam for Ballistic Trauma Application

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Abstract

Personal body armor remains essential in modern warfare for protection against high-velocity projectiles. Hard armor plates effectively prevent penetration; however, projectile deceleration transfers substantial kinetic energy to the wearer. Such energy transfer leads to non-penetrating injuries referred to as Behind Armor Blunt Trauma (BABT), which may cause rib fractures, liver rupture, internal bleeding and severe tissue contusion. Injuries of this nature can be life-threatening even without perforation. Conventional trauma pads commonly use heavy rubber sheets or multilayer textiles, increasing overall system weight and contributing to soldier fatigue.

The present thesis investigates the development and characterization of lightweight microcellular polymer foams intended for trauma mitigation pads. These foams function as efficient energy-absorbing layers while maintaining low areal density. Two manufacturing routes were explored. Solid-state batch foaming enabled laboratory-scale fabrication with controlled cellular morphology. Tandem extrusion foaming provided a pathway toward continuous and scalable production. Modifications to the extrusion system included

integration of a syringe pump for controlled gas dosing and custom stainless-steel piping for carbon dioxide delivery. Process optimization facilitated the formation of refined microcellular structures.

Mechanical characterization covered multiple strain-rate regimes. Quasi-static compression testing established modulus and plateau stress behavior. Low-velocity impact response was examined using a drop-weight configuration. High-strain-rate properties were evaluated using a modified Split Hopkinson Pressure Bar equipped with polymeric bars to reduce acoustic impedance mismatch. Results confirmed pronounced strain-rate sensitivity, with increased stiffness and improved energy absorption under dynamic loading.

Ballistic validation employed a single-stage gas gun with 9×19 mm Full Metal Jacket projectiles. Hard armor plates backed by the developed foams were tested and Roma Plastilina® clay was used to quantify Back Face Signature (BFS). Progressive cellular collapse under impact dissipated kinetic energy through plastic deformation and localized adiabatic heating. Low acoustic impedance of the foam contributed to partial reflection of stress waves, thereby limiting peak stress transmission to the torso.

Experimental findings demonstrate effective reduction of BFS values to survivable limits in accordance with BIS and NIJ standards. Performance remained comparable to commercial trauma foams while achieving lower areal density. Weight reduction enhances mobility without compromising protection. The research establishes a structured framework for designing soft armor backing systems and confirms that microcellular polymer foams provide a balanced solution for ballistic protection and operational comfort.