

ABSTRACT

This study investigates the operational behavior of soft armor panels (SAPs), focusing on the mechanical and frictional properties of individual fabric layers as primary drivers for dissipating projectile kinetic energy. During their service life, these materials are subjected to multiple ballistic impacts and environmental stressors, specifically long-term ultraviolet (UV) irradiation, which induces deterioration in ballistic performance. To optimize the experimental workload, a Finite Element Method (FEM) framework was developed to predict the ballistic response of both pristine and UV-aged multilayer fabrics. This model, which accounts for multiple impacts at diverse locations, was parameterized using experimental data from yarn pull-out tests and Universal Testing Machine (UTM) characterization. The simulations were validated under conditions compliant with National Institute of Justice (NIJ) standards. Furthermore, the study established the critical distance between successive impacts, quantifying the influence of cumulative damage on structural integrity. Findings indicate that energy absorption degradation is a function of UV exposure duration (32 h and 64 h), showing high fidelity to experimental observations. Additionally, short-duration thermal exposure (annealing) was found to reduce mechanical strength. Microstructural characterization—utilizing FTIR, XPS, and Raman spectroscopy—elucidated the chemical degradation mechanisms responsible for the loss in load-bearing capacity, while Atomic Force Microscopy (AFM) revealed a concomitant increase in surface roughness. To enhance the performance of the fabrics, a surface treatment utilizing silica nanoparticles was implemented. The inherent stiffness of the silica increased the coefficient of friction (COF) by 77.7% and improved mechanical properties, specifically increasing the modulus by 7% and ultimate stress by 20%. Notably, silica-coated samples exhibited negligible mechanical degradation following annealing, demonstrating superior environmental resilience and suitability for prolonged field deployment compared to virgin panels. Finally, a 3D FEM analysis was conducted to predict residual velocity in 8-layer armor configurations. This research underscores the efficacy of hybrid fabric constructions—incorporating carbon, Kevlar, and glass fibers—and provides a numerical basis for optimizing stacking sequences to design the next generation of high-performance soft armor panels.

Keywords: Ballistic performance, Coefficient of friction, microstructure, UV irradiation, Finite element model, hybrid constructions, surface treatment.