Attenuation of Low-Density Projectiles by Fabric in High-Rate Impacts

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ABSTRACT – Protective clothing can mitigate injuries from high-rate impacts, particularly from low-density projectiles such as sand, rocks, and debris. This study evaluated the velocity attenuation effects of denim and nylon fabrics when impacted by spherical projectiles of varying sectional densities. Building upon previous work quantifying skin penetration thresholds using porcine limbs, this study assessed whether fabric interaction alone—prior to tissue contact—can meaningfully reduce projectile energy. Taut denim reduced projectile velocity more effectively than loose-fit configurations or nylon. Attenuation percentage was inversely related to both initial velocity and projectile sectional density. These findings may inform the design of protective clothing for military and industrial applications, particularly where nonmetallic fragment threats are prevalent.

INTRODUCTION

Soft tissue injuries from high-rate projectile impacts are common in explosive and industrial environments, often caused by low-density debris such as sand and small fragments (LeSueur et al., 2024). Prior work has focused on the penetration mechanics of porcine skin, revealing a strong relationship between penetration risk and the projectile's sectional density and impact velocity. An exponential decay relationship between the impact velocity with a 50% risk of penetration (V50) and sectional density was established for projectiles ranging from 0.3–5 g/cm² (LeSueur et al., 2024). Prior studies have investigated energy absorption characteristics of high-strength fabrics in high-velocity ballistic impacts (Tan et al, 2003). Similar studies investigated the effect of fabric configuration, shape and size, on its ballistic impact response (Nilakantan and Nutt, 2014). A similar methodology could be used to assess the velocity attenuation potential of common clothing materials in high energy projectile impacts. This study evaluates if the velocity attenuation fabric provides is profound enough that it could lower the risk of soft tissue penetration of a projectile's given initial velocity and sectional density.

METHODS

All tests were conducted using a helium-driven pneumatic launcher previously validated for skin penetration studies (LeSueur et al., 2024). Spherical projectiles were launched at fabric samples mounted orthogonal to the projectile's flight path and recorded using high-speed videography (40 kHz, nac Image Technology). The primary metric was percent velocity attenuation, calculated from initial and residual projectile velocities, derived through physics-based video analysis (Tracker, Aptos, CA).

Initial testing sought to determine the configuration with the most profound velocity attenuation. These tests involved 3/16" stainless steel and plastic projectiles with sectional densities of 2.48 g/cm² and 0.4491g/cm^2 respectively. Denim (~344 denier; areal density ~288g/m^2) and nylon ripstop (~210 denier; areal density ~68g/m^2) fabrics were mounted in two configurations: taut (under tension) and loose (~1 cm of slack to simulate bagginess). Sixteen tests were conducted to compare velocity attenuation across each configuration.

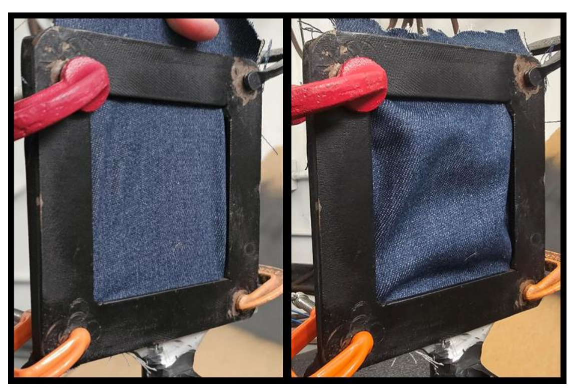

Figure 1. Taut (left) and 1cm loose standoff (right) fabric configurations.

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Initial testing suggested that taut denim attenuated the velocity most notably for both types of projectiles. Taut denim slowed the projectile about twice as much as baggy denim and about 20% more than taut nylon ripstop. For this reason, taut denim was chosen for the expanded series of tests. Seven projectiles of different material (steel, Si_3N_4, plastic) and sectional densities, ranging from 0.4–5 g/cm² were launched into this configuration; outlined in table 1 The fabric sample was repositioned by at least 2 cm horizontally and/or vertically between shots to ensure that each projectile impacted an undamaged section of material, thereby preventing partial or complete engagement with existing holes or compromised regions from prior impacts. For each projectile, initial velocities were selected to match previously determined milestones corresponding to a 10%, 50% and 90% risk of penetration (V_{10}, V_{50}, and V_{90}). Each condition was tested at least twice to assess variability and trend consistency for a total of 58 tests.

Projectile Diameter and Material	**Projectile Sectional Density (g/cm²)**	**Target Initial Velocity: V_{10}, V_{50}, V_{90} (m/s)**
3/8" Stainless Steel	4.955	80, 100, 115
3/16" Stainless Steel	2.477	110, 145, 160
3/8" Si3N4	2.063	100, 130, 160
1/8" Stainless Steel	1.652	135, 170, 190
3/16" Si3N4	1.031	Na*, 180, 200
3/8" Plastic	0.870	150, 185, 220
3/16" Plastic	0.449	220, 240, 265

Table 1. Test matrix: projectile diameter & material, sectional density and target initial velocity. *Note: no tests were conducted at V10 for 3/16" Si3N4 projectiles.

RESULTS

Initial testing showed that taut denim attenuated projectile velocity by approximately 10%, while the loose (baggy) configuration reduced it by only ~5%. Ripstop nylon, even in the taut condition, provided only ~7% attenuation, indicating that both fabric type and tension influence performance.

For all projectile types tested against taut denim, attenuation percentage decreased as both sectional density and initial velocity increased. Low-density projectiles such as 3/16" plastic ball bearings exhibited velocity reductions of >10% at low velocities, but attenuation dropped below 5% at V_{90}. Steel and ceramic projectiles with higher sectional densities (~3–5 g/cm²) showed minimal attenuation (<3%), even at V_{10} velocities.

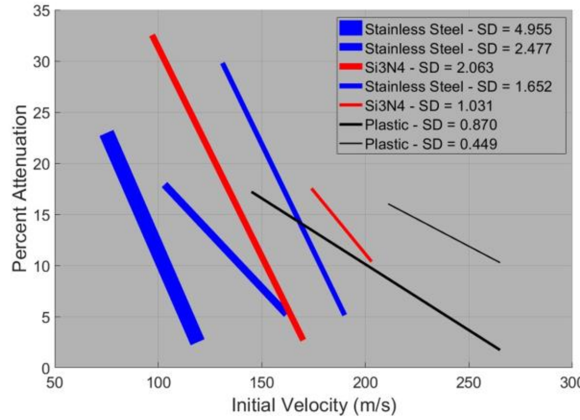

Figure 2. Attenuation percentage from taut denim compared to initial velocity for each projectile sectional density.

DISCUSSION

These results demonstrate that clothing material and fit can meaningfully attenuate small projectiles. Even modest attenuation (~5–10%) may prevent penetration in cases where initial velocity is just above the V_{50} threshold (LeSueur et al., 2024). This effect would also be more prevalent as initial velocity decreases, lowering risk of penetration at V_{10} velocities more noticeably compared to V_{50}. This is particularly relevant for low-density debris impacts in combat zones, industrial settings, or improvised explosive environments.

The relationship between attenuation and sectional density reflects the momentum retention of heavier projectiles, which deform fabrics less and transfer more energy. Fabric stretch and tension likely affect the time and distance over which energy is dissipated. This was observed when comparing the loose and taut configurations. The projectile would stretch the loose fabric taut as it engaged with it, resulting in higher relative deformation. This deformation results in a relatively inefficient position for the fabric to resist high energy impacts. Prior studies have shown that projectile-tissue interaction is sensitive to impact mechanics including velocity, orientation, and surface compliance (Koser et al., 2022; LeSueur et al., 2023).

This study supports incorporating fabric effects into finite element models of fragment impact to more accurately predict skin injury likelihood. Future work should consider multilayer garments, the role of body curvature and soft tissue compliance, and angle of incidence in real-world protective applications.

CONCLUSION

Common fabrics, such as denim, can attenuate the velocity of small projectiles, particularly when stretched taut. This attenuation is greatest for cases with low-density projectiles and with low initial velocities. This attenuation may result in impact velocities below injury thresholds, even when initial velocity would've been expected to cause injury. These results extend prior work on skin penetration mechanics and highlight the value of integrating fabric characteristics into protective gear development and modeling efforts.

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