From Low- to High-Speed, From Single to Multiple Threats: How Textile Materials Deliver Effective Protection

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Abstract

Protective structures now face a continuum of loading conditions, from a quasi-static needle peak to a hypervelocity fragment, and threats ranging from a single knife thrust to combined ballistic-and-blast events. Armouring solutions must reconcile ballistic and blast performance with weight and cost, while personal protection must reconcile ballistic and stab performance with comfort and cost. Meeting both targets calls for materials whose multi-scale architecture, from filament to yarn to fabric, can be tuned rather than replaced for each threat. This paper reviews how 3D warp interlock fabrics and derived textile composites, developed at GEMTEX laboratory, deliver such adaptative and protective solutions.
3D warp interlock fabrics bind several weft layers with warp yarns in one weaving step, tailoring in-plane stiffness, through-thickness cohesion and formability. For soft protection, needle-puncture testing (ASTM F2878) was adapted to a cylindrical, finger-shaped surface, and stab tests on six-ply assemblies of five interlock architectures showed the orthogonal-through-thickness structure gives the shallowest penetration depth. A seamless, directly 3D-woven female body armour, formed without cutting or stitching over the bust area, was validated against NIJ 0101.06 Level IIIA and transferred to TIBEKA Protections. Auxetic composites with re-entrant honeycomb architecture, characterized by stereo-DIC and compression testing (Poisson's ratio -0.17), were developed for CROR blade-fragment ejection and electric-vehicle noise reduction.

For hard protection, low-velocity impact tests on 2D and 3D woven composites showed architecture becomes decisive only above a damage threshold. A ceramic-faced 3D interlock composite defeated 12.7 mm AP ammunition (MIL-PRF-46103E), with 3D backing showing far less delamination than unidirectional laminates. A mono-impact FSP methodology (600-1742 m/s) mapped IED fragments and hypervelocity threats onto one protection envelope for armoured vehicles, and distinct rupture modes were linked to interlock type. Full-thickness 3D composites matched hybrid 3D/2D solutions at equal areal density, and full-width 3D backing reduced blast intrusion deformation versus steel or 2D composite backings alone.
Across this speed and threat spectrum, 3D warp interlock fabrics provide a customized design platform, validated against ASTM, NIJ and MIL standards and transferred to industrial and defence partners. Further work targets multi-hit performance, durability, comfort and process scale-up.

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