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FEATURE

Ballistic composites – protecting the protectors

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It seems scarcely credible that thin polymer fibers, bound together in resin, can stop projectiles ranging from a hand-gun bullet to a high-power rifle round, but they can and have done so, saving many lives in the process. Composite body armor protects a wide range of civilians from security guards to police officers and from bailiffs to VIPs.

But of course, it is military forces who are the leading user group. Traditional solutions for 20th Century military armor, based chiefly on steel and ceramic plates, were really too heavy for soldiers, indeed for many vehicles as well. Composites have increasingly proved to be the answer, being much lighter for the same stopping power and more pliable. Certain polymer composites show, when appropriately engineered, remarkable energy dissipation properties, being able to absorb the kinetic energy from bullets and other high-speed projectiles before these can harm their human targets. They can also protect against knives.

Various mechanisms account for this. Pushing fibers aside against their stiffness and the hold exerted by the composite they are part of, absorbs energy and the greater the number of fibers encountered, the stronger is the effect. Still more energy is absorbed as fibers become stretched during contact with projectiles, elongation-before-break being an important variable for armor designers. A third mechanism is that of delamination, whereby energy is absorbed in parting fibers from their resin containment medium.

Yet another mechanism occurs in woven fabrics where the woven intersections slow down the shock waves propagated along the fibers from the impact point, absorbing energy as they do so. This does, however, increase the strain within the material and when this exceeds what the material can tolerate, penetration can occur. Hence whether to use wovens or non-wovens is a matter for careful consideration by protection designers (Figs. 1–3).

According to ballistic specialists with Swiss-headquartered composites firm Gurit AG, stopping a bullet has three distinct stages. First is the blunting of the projectile so that its penetrating power is degraded. Second is a slowing phase and third is the catching of the round so that it is retained within the protective garment.

Laminates are designed to maximize the effectiveness of these stages. Outer layers that provide controlled delamination on impact are effective in deforming the tip of a projectile, thereby blunting it. Certain non-polymer composites, for instance those that are ceramic based, may be harder than polymer composites and therefore more effective in this phase. Even so, reinforced plastics often provide the best balance of weight, anti-ballistic performance and cost.

Underlying composite layers subsequently absorb kinetic energy progressively as more and more fibers are displaced and

FIG. 1

Flack jackets based on Kevlar or other proprietary aramid can be worn under normal clothing by both men and women. Image licensed by Shutterstock.

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FIG. 2
Kevlar helmet with camouflage cover and protective goggles. Image licensed by Shutterstock.

stretched. Composites used in body armor, where structural strength is less of a requirement than in vehicle protection, generally have very high fiber content, up to 80% or more, and specialized polymer fibers are used. Even in armor that has a ceramic outer face, this is generally backed by composite laminate to meet the slowing and catching requirements, including of penetrative fragments that are expelled from improvised explosive devices (IEDs) and fragmentation rounds (such fragments are known as spall).

IEDs deliver blast, fragments and fire so that combined protection against these is desirable. Materials that mitigate these effects as well as being environmentally tolerant – to moisture, heat, etc. – are in demand. Another required attribute is that they should be able to resist not just single hits but also repeated shots, as from a machine gun.

Body armor is typically based on woven and non-woven fabrics that are flexible enough to provide wearers with freedom of movement while still possessing high anti-ballistic properties. Many garments incorporate extra protection in strategic areas such as over the heart; this can take the form of plates of composite, ceramic, metal or hybrid material inserted into containment pockets incorporated in the garment. Such inserts are typical of protection that is rifle ballistic rated since fabrics alone cannot normally stop a rifle round traveling at 800 m/s whereas they can prevent penetration by a hand gun bullet traveling at half that speed. Although body armor designed to defeat rifle fire is inevitably more rigid than fabric-only garments, keeping the armor inserts separated ensures an adequate level of garment flexibility for most purposes.

Nylon start

An early example of the transition from metals to composites for personnel protection was the British Army's GS Mk 6 combat helmet, issued during the 1960s. This had an outer shell of ballistic nylon impregnated with a 50:50 mix of phenoformaldehyde and polyvinyl butyral (PVB) resins, this matrix accounting for 20% of the composite's weight. The shell comprised 23 layers of plain-weave 290 g/m^2 nylon, weighing 1 kg for the medium size of helmet. An inner impact absorbing layer of high-density polyethylene (HDPE) foam brought this weight up to 1.3 kg. Fiberglass, and even combined nylon and fiberglass, were also tried during those early years, providing some benefits over nylon.

During the 1970s, the US Army was to adopt para-aramid fibers for head protection, albeit in resins similar to those used by the British. PVB-based resins were readily Beta-staged into a prepreg that could then be hot-molded to the tight complex curvatures required for combat helmets. Aramids, the best known of which are DuPont's Kevlar and Twaron from Teijin (the Netherlands and Japan), subsequently spread from helmets into body protection. The Kevlar 'flak jacket', for instance, became almost a generic, initially for ballistic vests that protect against fragments from shells, grenades and other munitions, but also later for garments that are substantially bullet-proof.

Para-aramid fibers have a rigid rod-like molecular structure that provides high-tensile strength, high elongation-to-break and good damage tolerance. They are also inherently non-flammable. Today they tend to be embedded in more contemporary matrices, typically epoxy or phenolic. The resulting composites are heavily fiber dominated. Like other specialists in ballistic fibers, DuPont Protection Technologies has worked hard to optimize its base material

FIG. 3
From police officers to soldiers, Dyneema Force Multiplier Technology is protecting personnel around the world.

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