Enhancing the performance of thermoplastic-based ballistic helmets

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Current research in materials and manufacture envisages significant improvements with implications for process control, tool technologies, helmet-mounted sensors, and in situ sensing.

Future head protection for US warfighters will benefit from advances in several areas, including materials, manufacturing, and sensor technologies. Enhancing a warfighter’s performance no longer means simply reducing system weight or increasing ballistic protection. It has come to include “wiring” the warfighter to an extremely dynamic and powerful network, and providing the soldier with a range of sensors: visual, IR, communication, blast detection, and others. The technical challenge is to minimize the weight and operational burden these sensors may incur. Figure 1 shows some of the alternative concepts under consideration for helmet sensor integration. To properly address the problem, the US Army is looking to new materials, processes, and concepts that will use sensor technologies in two distinct ways: mass-efficient integration of sensors into the helmet and new process sensors to ensure optimal fabrication and ballistic performance in mass-produced helmets.

A ballistic helmet might appear to be an almost trivial item to manufacture by comparison with other Army systems, especially those that make use of polymer composites. Both in terms of geometric complexity and materials, it would seem a simple matter to form a 2D sheet into a 3D shape. But therein lies the essential challenge: to uniformly retain properties of sheet goods in shell form. The problem would indeed be inconsequential were it not for the ultimate properties of the shell and the degree of variability induced by the forming process itself.

Historically, some helmet properties are enhanced by forming. Classic armor materials (e.g., steel), when worked into shell form, actually exhibit work hardening that improves ballistic or structural properties. However, the dilemma becomes dramatically apparent when one shifts to organic, man-made fibers in either woven or cross-plied sheet goods. Fiber spreading, distortion, stretching, and the like can enrich certain areas and deplete others, resulting in nonuniform properties. Inasmuch as a threat, such as shrapnel or a bullet, can impact the helmet from any direction, it is desirable to have uniform ballistic properties throughout. At the very least, the lowest level of ballistic performance should be well above defined performance criteria.

Although the US Army has always made pioneering use of new materials and processes, an important caveat requires confidence in them before they replace an entire generation of proven equipment. As such, an Army helmet is a physical item that also reflects a rationale and the result of careful design, testing, refinement, and quality control. The introduction of the aramid Kevlar, for example, constituted a materials revolution in which an organic, man-made fiber replaced steel in a military application and, at the same time, provided an unprecedented boost in ballistic mass efficiency.

The current Army combat helmet (ACH) represents an improvement in ballistic performance and user interface (e.g., with weapons and body armor), while a new suspension system...
Figure 2. Preforming represents a key area for innovation. Automated helmet assembly for thermoplastic composites aims at high uniformity in the finished product.

Figure 3. Novel approaches to design and manufacture of the ‘chassis’ for structural support can reduce assembly costs.

provides greater comfort. However, like the predecessor personnel armor system ground troops (PASGT) helmet, the ACH still uses aramid/thermoset composites and processes that are more than 30 years old, albeit with advances in the aramid class of fibers themselves. Although not new, materials such as DuPont’s Mark III, Honeywell’s Spectra, and DSM’s Dyneema have demonstrated significant advantages over conventional aramid/polyvinyl butyral phenolic combinations in other applications, and they warrant investigation in terms of future helmet applications.

Various laboratories and organizations within the Army currently focus on reducing the risk of adopting a new generation of thermoplastic-based ballistic materials in helmet systems that have already demonstrated significant mass efficiency. The challenge remains to reliably and consistently retain performance gains in “as-manufactured” helmets. While many materials exhibit desirable structural and ballistic properties, one group in particular shows considerable promise: the thermoplastic-based resins and fibers, including ultra-high molecular weight polyethylene (UHMWPE) and the thermoplastic aramids.

It is worth noting that the move away from detailed specifications, which formerly stipulated types of fibers and resins as well as processing agents and methods, has permitted manufacturers to choose and combine virtually any materials to satisfy performance goals. As a consequence, defining such goals becomes critical, as does awareness of the benefits and limitations of materials and processes. Other more fundamental considerations, given that a ballistic helmet may enter the Army inventory, include generating awareness of materials availability, supplier capacity, priority use of materials for competing applications (e.g., vehicles, aircraft), and foreign sources of materials.

Dyneema and Spectra, currently more expensive than aramid fibers, will require a different set of processing technologies if they are to remain competitive with current ACH manufacturing cycles and production costs. The Army Research Laboratory, in collaboration with Natick Soldier Research, Development, and Engineering Center (NSRDEC) and Program Executive Office (PEO) Soldier initiated a focused effort to identify technology barriers associated with thermoplastic ballistic materials. Two basic areas have emerged as candidates for innovation. Preforming, the first of these areas, aims to maximize performance, ensure uniformity, and provide excellent ballistic protection while minimizing waste, scrap, excessive variability, and higher costs associated with “touch” (human) labor (see Figure 2). The second area focuses on developing tooling and molding technologies for heating, high-pressure consolidation, and rapid cooling of thermoplastic materials into a neat net helmet form, employing novel design approaches for mass-efficient retention of structural properties. The chassis approach shown in Figure 3 is being considered for a prototype platform that would enable integration of sensor cables, wiring, sockets, and power sources more efficiently, while also providing much needed secondary structural reinforcement to the helmet shell.

The NSRDEC and PEO efforts are still under way, but they have already conclusively demonstrated that it is possible to obtain significantly improved performance from a helmet with these materials and a new set of process technologies. Innovative sensors that can provide in situ temperature and high-pressure measurements during the consolidation phase of helmet fabrication are much needed. Such sensors would enable effective process control and stronger correlation of upstream process conditions and history with end-item ballistic and structural performance. As part of its final year objectives, an ongoing Army Mantech program executed by the Army Research Laboratory intends to explore new process sensors and process control technologies, including for helmet tooling.

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References