LIGHTWEIGHT ARMOR AND ITS USE ON THE BATTLEFIELD

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Abstract
Armor materials are remarkable: Able to stop multiple hits and save lives, they are essential to our military capability in the current conflicts. But as threats have increased, armor systems have become heavier, creating a huge burden for the warfighter and even for combat vehicles. In this article is describe material used for personal armor, armored vehicles and transparent armor.

Keywords: ballistic armor, lightweight armour, armour classification

1 Introduction

Since the beginning of armed conflict, armor has played a significant role in the protection of warriors. In present-day conflicts, armor has inarguably saved countless lives. Over the course of history and especially in modern times the introduction of new materials and improvements in the materials already used to construct armor have led to better protection and a reduction in the weight of the armor. Body armor, for example, has progressed from the leather skins of antiquity, through the flak jackets of World War II to today's highly sophisticated designs that exploit ceramic plates and polymeric fibers to protect a person against direct strikes from armor-piercing projectiles. The advances in vehicle armor capabilities have similarly been driven by new materials. But even with such advances in materials, the weight of the armor required to manage threats of ever-increasing destructive capability presents a huge challenge. For example, body armor, which presently constitutes almost 30 percent of a soldier's fighting load, is the single largest weight carried by an Army rifle squad. For vehicles, up-armored Humvees have reached the limit beyond which armor cannot be added without "compromising essential vehicle capabilities."

The challenge for protective material developers, made clear by current military engagements, is twofold: (1) to ensure the rapid (re)design and manufacture of armor systems optimized against specific threats and (2) at the same time, ensure that these systems are as lightweight as possible. As described above, many of the advances in the performance of lightweight armor have historically come from the introduction of new or improved materials. However, it has become increasingly difficult to produce new materials with properties that allow the design of complex new armor systems or the rapid iterations of such designs. Not only must a material be quickly identified, but it must also be reliably produced which is not currently possible with the extensive, costly, and time-consuming practice that is perhaps best described as "build it, shoot it, and then look at it."

2 Classification of lightweight composite armor

Type I 5.56 mm

Class 1 - M855 lead ball with steel tip projectile at muzzle velocity (3100 ft (945 m) per second).

Type II 7.62 mm (0.30 caliber)

Class 1 - Lead or mild steel core ball projectile at muzzle velocity (2850 ft (869 m) per second).
Class 2 - Hard steel core armor piercing (AP) projectile at muzzle velocity (2850 ft (869 m) per second).
Class 3 - Heavy density core sabot launched armor piercing (SLAP) projectile at muzzle velocity (4000 ft (1219 m) per second).

Type III 12.7 mm (0.50 caliber)

Class 1A - Mild steel core ball projectile at 1000 meters range (1600 ft (487 m) per second).
Class 1B - Mild steel core ball projectile at 500 meters range (2000 ft (610 m) per second).
Class 1C - Mild steel core ball projectile at muzzle velocity (2850 ft (869 m) per second).
Class 2A - Hard steel core armor piercing (AP) projectile at 1000 meters range (1600 ft (487 m) per second).
Class 2B - Hard steel core armor piercing (AP) projectile at 500 meters range (2000 ft (610 m) per second).
Class 2C - Hard steel core armor piercing (AP) projectile at muzzle velocity (2850 ft (869 m) per second).
Class 3 - Heavy density core sabot launched armor piercing (SLAP) projectile at muzzle velocity (4000 ft (1219 m) per second).

Type IV 14.5 mm

Class 1 - Hard steel core armor piercing incendiary (API) B32 projectile at muzzle velocity (3250 ft (991 m) per second).

Class 2 - Hard steel core armor piercing incendiary (API) BS-41projectile at muzzle velocity (3250 ft (991 m) per second).

Although the testing and definitions described above hold for all classes of armor systems, the threats and the design philosophy are completely dependent on how the armor is used. Thus, each of the three applications focused on in this report (personnel, vehicle, and transparent armors) are treated separately. It should be noted that military armor systems are currently purchased according to performance specifications that are classified. Descriptions of threats and designs in this study are taken from the open literature and documents approved for public release. As such, they are only illustrative of current threats and designs.

2.1 Personnel protection

Modern armor for personnel protection includes both body armor and combat helmets. The threats for which personnel armor is designed are small-caliber projectiles, including both bullets and fragments. The level of ballistic protection of personnel armor is taken as the total kinetic energy of a single round that the armor can stop [1]. The stan- dards set by the NIJ are for typical ballistic threats, although not specifically those for military body armor, which are classified. Note that a Type IV projectile has more than 7.5 times the energy of a Type IIA projectile. In addition to surviving the impact of specific projectiles, there is generally a requirement to withstand multiple hits on the same armor panel. For armor meeting NIJ Type IIA and Type III standards, panels must demonstrate the ability to survive six hits without failure. Only Type IV has no multi-hit requirements. Personnel protection armor is also often designed against fragments. Finally, for body armor, as previously mentioned, stopping penetration is not the only issue. It is also important that when stopping the projectile, the armor itself does not deflect to an extent that would severely injure the wearer. This puts an additional constraint on body armor systems.

Fig. 1 *Interceptor body armor*

The design of armor for personnel protection depends on the specific threat. For fragments and lower velocity penetrators, vests are typically made from polymer fibers. Advances in fibers for personnel armor began with the use of fiberglass and nylon. These were followed in the late 1960s by polyaramid fibers (DuPont PRD 29 and PRD 49), now called Kevlar. Later, high molecular weight polyethylene fibers, made of Spectrashield and Dyneema, were also used as backing in vests. Zylon, made of polybenzobisoxazole (PBO), has also been considered. Thus, the primary factor in the design of armor for vests is the selection of the fiber. When the threat increases to rifle rounds, including armor-piercing projectiles, ballistic fabric alone is insufficient. Stopping these threats requires adding a ceramic plate to the outside of the vest. The hard ceramic blunts and/or erodes the projectile nose, which increases the projected area of the projectile and spreads the load across more of the fabric

[1]. It is the combination of two independently developed materials a ceramic faceplate and a fiber fabric that constitutes the armor system and provides overall protection. The combination creates a complex system where the performance of the ceramic and the polymer backing (vest) are intimately connected. The currently fielded body armor, the Interceptor body armor (IBA), makes use of the combination of ceramic and fiber. The main component of this armor is the improved outer tactical vest, which provides protection against fragments and 9-mm rounds [2]. Enhanced small-arms protective insert (ESAPI) ballistic plates and enhanced side ballistic insert plates are inserted into plate carrier pockets in the polymeric vest. These plates can withstand multiple small-arms hits, including armor-piercing rounds [3]. IBA can stop small-arms ballistic threats and fragments, thus reducing the number and severity of wounds. An improvement, the X small-arms protective insert, is designed for "potential emerging small arms ballistic threats." The deltoid and axillary protectors, an integral component of the improved outer tactical vest, extend protection against fragments and 9-mm rounds to the upper arm areas. The combination of ceramic inserts and polymeric fibers in the IBA vest is an example of how particular arrangements of specific materials make up a typical armor system. The complexity goes even further: A change in threat can drastically change the performance of a given armor system.

2.2 Vehicle armor

Like personnel armor, vehicle armor is also typically required to protect against small-caliber projectiles and fragments. In addition, however, it is required to stop a host of other threats. These include medium-and large-caliber ballistic threats (20-140 mm) [4]; shaped charge munitions and chemical energy munitions. Rocket-propelled grenades are ubiquitous in the world of terrorists owing to the efforts of the countries that manufacture them to market them to developing countries. Because little effort was made to destroy ammunition dumps during the invasion of Iraq, the artillery projectiles left behind have since been used to fashion improvised explosive devices. Countries such as Iran have taken it upon themselves to manufacture many sizes of projectiles that are nominally concave metal disks propelled by large cylindrical high-explosive charges. Specific requirements for the multithreat environment to which truck and tactical wheel systems are exposed are defined by the Army's long-term armor strategy specifications, which are classified.

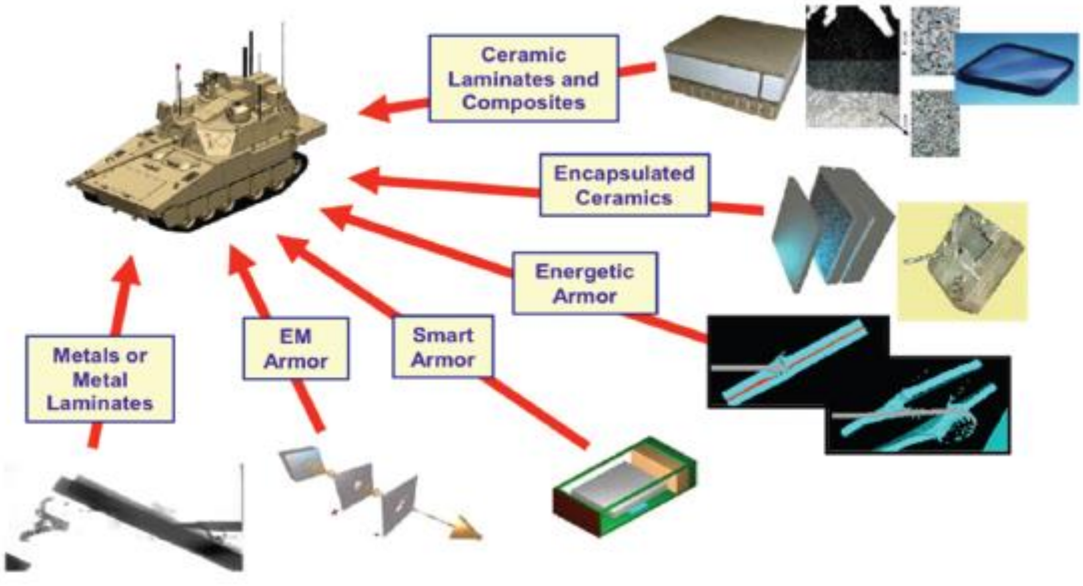

Fig. 2 *Examples of vehicle protection*

The design of armor systems for vehicles depends on the size of the vehicle, the threat or threats the vehicle is likely to encounter, and, equally important, the weight of the armor that the vehicle can handle. Since the early days of tanks in World War I, metal has been the primary armor material used for large combat vehicles. This article considers only the passive armor systems; electromagnetic, energetic, and smart armor are beyond its scope, as are reactive armor systems. As with personnel protection, passive vehicle protection is generally a complicated arrangement of material layers, each serving a different role in the overall protection schedule. Figure 3 schematically depicts one such arrangement that comprises six layers of various materials, including ceramics, metals, and polymers [5]. Note that the entire system serves many more functions than just protection against projectiles.

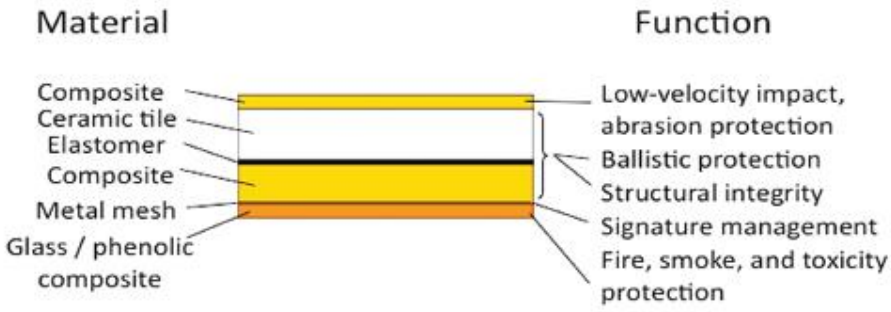

Fig. 3 *Schematic of vehicle armor protection system*

Unlike designs for protecting personnel, armor designs for vehicles are less constrained in thickness. This allows for a concept known as "spaced armor," another option for the arrangement of armor. In spaced armor, a thin armor plate is separated from the main armor system with the goal of breaking up or disrupting the projectile, thus making it easier for the remainder of the armor to stop it. This concept was used by the Germans in World War II [6] and in various armor configurations since. It should also be noted that, even if the threat does not completely exit the armor, pieces of the back face can be accelerated by the shock wave, creating spall, which can have sufficient velocity to considerably damage people and equipment inside the vehicle. Thus, armor design must minimize behind-the-armor damage, which can adversely affect the survival of the crew even if the projectile is stopped [7].

2.3 Transparent armor

The windscreen and side windows of vehicles such as IFV and trucks are an important application for transparent armor. At the moment, the window is intended to protect the threats against armor-piercing, as well as high speed fragments. Furthermore, it must be capable of withstanding multiple Hits and the fracture so as to maintain their structural Integrity and transparency. Advanced applications transparent armor often require additional protection electromagnetic fields or lasers. This study, however, will cover only the ballistic requirements of transparent armor. These specs also set forth criteria for the environmental effects of transparent armor. As with other documents on applications of armor, DTA184044, the document that describes the threats that must be defeated, is contained in a classified appendix and so cannot be elaborated on here.

In contrast to conventional opaque ceramic armors, the design of transparent armor is often driven by the multi-hit requirement, a requirement mostly achieved by layering. A typical transparent armor uses a layer of glass or glass ceramic followed by a layer of polycarbonate and then other similar layers until seven or more have been stacked and bonded with polyvinyl butyral adhesive layers. While the backing of transparent armor is primarily polycarbonate, other polymeric materials, such as polyurethane, are showing some potential. Most current armor windows are laminates of glass and plastic [8]. The three main transparent ceramic candidates are currently aluminum oxynitride (AlON), magnesium aluminate spinel ($MgAl_2O_4$), commonly referred to as spinel, and single-crystal aluminum oxide (Al_2O_3-sapphire) [9].

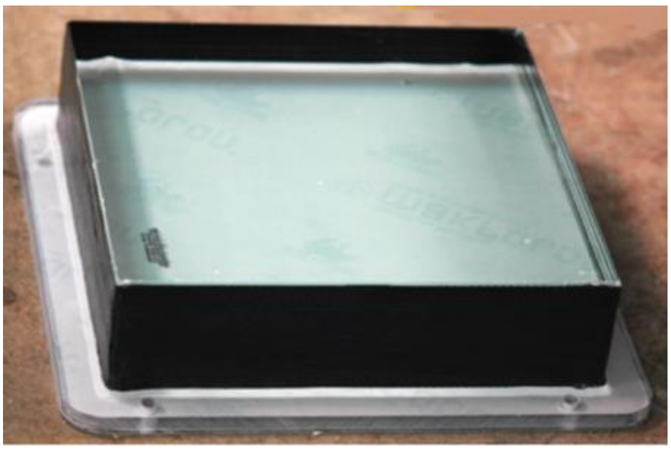

Fig. 4 *Example of transparent armor for a vehicle window*

3 Conclusion

The goal of armor system development is to continually decrease the weight that is, to increase Em-required to protect against a given threat or to not increase the weight required to protect against a greater threat. According to the Army, new armor systems can in fact be delivered to the field relatively quickly. However, this is generally because new armor configurations and materials are not radically different from those that have already been demonstrated to be effective. In response to a new threat against which current armor systems fail, a new armor system concept including geometry, configuration, and materials is chosen that, from experience, designers hope will defeat the new threat.

Changes in geometry can be as simple as adding thicknesses to various layers in an existing configuration; possible, but less likely, is an entirely new design. Materials are chosen from a set of available materials whose ballistic and blast performance have already been proven both as individual materials and combined with other materials. While much excellent materials research is under way, emerging research materials are seldom, if ever, chosen for new armor because there is no way to directly tie how they perform in a research environment to how they will perform in the actual armor configuration. Moreover, most nonarmor applications materials are chosen according to their bulk quasi-static properties, such as hardness, strength, and toughness, even though such properties do not always predict the materials' ballistic or blast performance.

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