THE ROLE OF CONTEMPORARY FERROUS AND NONFERROUS MATERIALS IN BALLISTIC PROTECTION OF MILITARY VEHICLES

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Introduction

Metallic armor is the most mature class of armor materials and is still widely used for ballistic protection today. Although the materials for metallic armor are highly developed, new and innovative metallic armor systems are being used to improve the ballistic protection (while reducing the weight) of various weapon systems. Historically, most metallic armor evolved from designing materials to meet structural or other requirements rather than from designing specifically for ballistic protection. This design paradigm is changing; partly to meet the requirements for armed forces transformation to a lighter, more survivable and efficient force [1]. Metallic armor systems are now being designed to optimize mass, space and cost efficiency.

Monolitic metallic armor

Development of steel armor

Steel armor comprises the bulk of past, present, and likely the future armor materials. This is because it possesses a number of desirable attributes that should not be overlooked. Steel is inherently inexpensive due to the low raw material and fabrication costs, as well as enormous commercial steel production capacity. It provides good ballistic protection from a wide spectrum of treats with excellent multi-hit capability. It can be easily cut, machined, formed, and welded, is easily field repairable, and has good degradation resistance against the ambient environment.

In the decade following the World War II, there was an intense period of investigation into the physical metallurgy and mechanical properties of high strength steels. It was found that steel at maximum hardness, but with enough toughness to resist cracking provided the best ballistic performance [2-4]. The optimum of strength and toughness was obtained with a medium-low carbon, low alloy steel tempered in such a way that martensitic effects dominate over residual austenite fractions. These steels are much more ductile than their more austenitic counterparts, and thus are far better at absorbing and mitigating kinetic energy from shock and blast – these are desirable qualities in armor materials.

a) b)

Fig. 1. a). RHA and CHA has been used in tanks since World War II such as in the M60 Patton tank, b) Light armored vehicle is partly composed of HHA

At present, the two major types of steel armors are: rolled homogenous armor (RHA) and cast homogenous armor (CHA), Figure 1a [5]. In these steels inclusions, sulfur, phosphorus and tramp element levels have been drastically reduced, while strength and particularly toughness have increased. RHA continues to be the benchmark with respect to which the most protection materials are judged.

High hardness steel armor (HHA) was developed for use against ball ammunition. Its composition is similar to RHA but it has a maximum of 0.32 wt. % carbon and is composed primarily of austenitic structures, which are very strong, hard and extremely crack-resistant but are brittle. This steel is extremely mass efficient against ball ammunition particularly at highly oblique angles of impact. The Light Armored Vehicle (LAV) upper part is made of this steel, Figure 1b [6].

Development of aluminum armor

Aluminum alloy 5083-H131 is a non-heat-treatable, strain-hardened aluminum-magnesium alloy. It is very resistant to cracking and stress corrosion cracking. It is readily weldable and corrosion resistant and has excellent to fragmentation threats. M113 Armored Personnel Carrier is made of 5083-H131, Figure 2a.

a) b)

Fig. 2. a) M113 Armored Personnel Carrier, b) US Marine Corps Expeditionary Fighting Vehicle

Aluminum alloy 7039-T64 is an aluminum-magnesium-zinc alloy that is heat treatable to a hardness higher than that of 5083. It exhibits better performance against ball and armor piercing (AP) threats than 5083 with some loss in performance against fragmentation threats. It is susceptible to stress corrosion cracking and thus is not recommended for future vehicles.

Aluminum alloy 2519-T87 is an aluminum-copper-manganese alloy that is heat treatable to hardness to those exhibited by 5083 and 7039. It exhibits better performance against fragmentation threats than 5083 and has almost the same performance against ball and AP threats as 7039. It has good resistance against stress corrosion cracking but poor resistance to general corrosion. The first production armored vehicle utilizing 2519 aluminum will be US army Marine Corps Expeditionary Fighting Vehicle, Figure 2b.

Besides the above mentioned, the other aluminum alloys which are used in armor in military vehicles include: 2024, 5059, 6061 and 7075.

Development of titanium armor

The high cost of weight-efficient titanium relative to steel has previously limited its application to aircraft armor where weight is a premium. However, recent investment in low cost titanium has enabled its application in advanced lightweight armored vehicles. The armor composition of 6 wt. % aluminum, 4 wt. % vanadium (Ti-6Al-4V) was developed by US Army. This material is used in the annealed condition rather than the much harder solution-treated and aged condition, as employed by other metallic armors. The best performance is normally obtained when this alloy is as soft as possible.

Magnesium and magnesium alloys

Magnesium has a remarkable low density of 1700 kg/m^3 (in comparison, Al is 2800 kg/m^3, Ti is 4950 kg/m^3, and steels are 7800 kg/m^3). Its density is close to those of polymers. Magnesium and magnesium alloys are thus among the lightest structural metals, and they are becoming increasingly important in the automotive and hand-tool industries [7]. The low density makes these materials very attractive for defense applications. Commercial magnesium alloys that can substitute for some aluminum alloys include AZ31 and ZK60.

Monolitic hybrid laminates

Metallic laminates

Dual hardness armor steel (DHA) was developed to achieve improved performance over HHA [1]. Armor piercing threats are typically defeated by fracturing them using a hard face plate, and the role of the softer back plate is to catch the debris. DHA steel has a 59-63 Rockwell C hardness (HRC) for the face plate and 50-53 HRC for the back plate. This is the best performance steel armor against small arms ammunition, both ball and AP, but is also the most expensive. It is difficult to form and weld, and large plates often have areas that are not completely bonded.

Metal/composite hybrids

Monolithic metallic armor is now routinely combined with a fiber/resin composite plates. The initial role of the composite was to serve as spall shield to minimize the trauma to the interior of the vehicle if the metallic armor is penetrated. Typically, the fibers which are used as reinforcements for the composites are aramid, high-performance polyethylene and glass. At present, not only as spall liners, metal/composite hybrids are used as structural and main ballistic protective items. The authors of this article have been working on research and development of metal/composite hybrid protection on T-72 tank which incorporates ballistic sandwich construction composed of central

woven glass roving/phenolic composite plate, 53 mm thick, and ballistic steel cover plates. The whole assembly being over 100 mm thick, Figure 3.
High hardness steel or titanium armor that has been tightly wrapped with a thin layer of aramid has been shown to have improved ballistic performances.

Metal/Ceramic hybrids
Typical metal/ceramic armor consists of a hard ceramic face supported by a metallic backing. As a concept proven with DHA, a hard strike face is very effective in breaking up the threat. Ceramics can have a higher hardness than the hardest steel and thus they are efficient material to break up, shatter, erode,

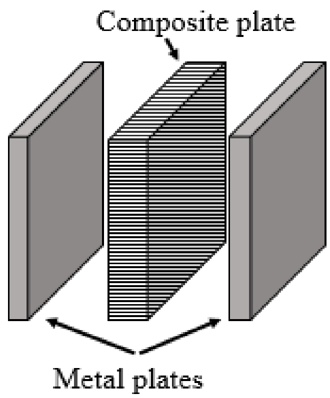

Fig. 3. Hybrid metal-composite armor system implemented in T-72 tank

and dwell the projectile before it hits the back plate. The metal back plate catches the fragments of both the ceramic and the projectile.

Metal/Ceramic/Composite hybrids
These systems utilize hard ceramic as the strike face to break up the threat and a metal to provide structure and catch fragments from the ceramic and projectile. Fiber/polymer composites are also used to catch any spall off the back of the metal.

Metal armor vs. fiber/resin composite armor
The main ballistic protective materials nowadays, besides ceramics, are metals/alloys and fiber/resin composites. The advantages of metallic over composite materials lies in their availability, cost, fabricability, durability, multi-hit capability, weldability and a broad spectrum of threats protection, among the others. These materials are the first choice for protection of ground vehicles where the weight is not of primer importance. Composite materials biggest advantage is in their superior strength/weight ratio which makes them the first choice material for lightweight structure for aero industry as well as for personal protection e.g. for military troops and police forces.

Conclusion

Advanced metallic armor materials continue to exhibit properties that cannot be matched by other materials. Some of the reasons for the large role of the metals include the fact that they are relatively cheap to produce, easily weldable, and able to play dual roles as structural materials and armor materials. The dual use potential and the economics of processing, metalworking and joining are likely to continue to make metallic materials strong candidates for major components of robust and affordable armor systems.

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