New Titanium Armor Application Provides Protection in a Lightweight Kit

Stephen Luckowski
Jeffrey Schutz

U.S. Army Armament Research, Development and Engineering Center (ARDEC)

ABSTRACT
The U.S. Army Armament, Research and Development Center (ARDEC) provides both lethality and gunner protection systems in support of the Army’s operations in Iraq and Afghanistan. ARDEC is the design activity for the Army’s standard gunner protection kit for HMMWV and Mine Resistant Ambush Protected (MRAP) vehicle platforms. This gunner protection kit, known as Objective Gunner Protection Kit (O-GPK) is designed and configured to provide U.S. soldiers enhanced protection against enemy rifle fire and improvised explosive device (IED) blasts and still allow full visibility. This Army-wide solution is made of steel.

In order to meet the requirements of a more specialized application, the Special Operations Command (SOCOM) requisitioned a titanium-based version of the O-GPK to support their operational needs. Titanium’s high strength would provide the needed force protection, while its lightweight would allow designers to meet these needs at a much reduced weight. This presentation will discuss the process of re-designing the O-GPK using titanium and the challenges faced. It will also discuss the advanced titanium processes and production equipment used to design, fabricate, and manufacture the titanium products.

GUNNER PROTECTION EVOLUTION
Gunner protection technology and production expertise has evolved quickly in the past three years (since 2005) in response to requests coming from the Iraq and Afghanistan operating theaters for better protection against evolving and increasingly asymmetric threats. In addition to sniper fire, vehicle commanders and gunners are routinely subjected to fragments and blast pressures from IEDs and roadside bombs.

Early ARDEC design responses included the Stryker Cupola Shield and first Gunner Protection Kit in 2005 and the Picatinny Blast Shield (PBS) in 2006.

Stryker Fire Support Vehicles (FSV) and Reconnaissance Vehicles (RV) in the field lacked sufficient protection for the vehicle commander. In addition, the rotating cupola on the Stryker vehicles imposed weight restrictions on the design that limited materials to either organic composites or titanium. ARDEC was able to leverage its previous work developing titanium welding and furnace technologies to rapidly design and prototype a satisfactory lightweight cupola shield. ARDEC expertise in concurrency of engineering and manufacturing ensured that the cupola design could be easily transitioned for high-rate production. Four hundred kits were initially fabricated at ARDEC’s pilot manufacturing facility and expedited to Operation Iraqi Freedom field units, while regular production capabilities were transferred to the industrial base.

The titanium-based cupola shield supplements the existing Stryker mounted gun shield, providing enhanced survivability with rear and side multi-hit ballistic protection and increased stability. The Stryker vehicle commander can rotate the cupola with a manual assist mechanism and motor that improves operation, especially at greater slopes. The unit also improves performance by shifting the system’s center of gravity toward the center of rotation of the cupola.

Gunner protection design challenges involved striking a balance between maximizing force protection and situational awareness for the warfighter while at the same time working to minimize overall weight and number of components. The ARDEC design team worked together with soldiers from Iraq to determine Gunner Protection Kit
requirements in December 2005. Building on established practices of concurrent engineering, where manufacturability issues are addressed during the design phase, the O-GPK team used in-house production-ready processes to build a prototype that was ready for testing by January 2006. A combined group consisting of ARDEC, Aberdeen, PM Tactical Vehicles, and TARDEC personnel verified and tested the prototype. On conclusion of field evaluation, a low-rate initial production (LRIP) run of 1000 units were delivered to Operation Iraqi Freedom in July 2006. O-GPK integrated development, which went from concept to production in an unprecedented six months, resulted in a new standard gunner protection kit for all Army tactical vehicles.

The O-GPK design has been adapted to a number of vehicle platforms in addition to the original M1114 version (including RG-31, RG-33, and MRAP vehicles) and has proliferated to other service branches including the Marines and SOCOM. Well-received in the field where it immediately proved itself by providing increased force protection while maintaining enhanced visibility and target acquisition, the O-GPK was voted one of the Army’s Top Ten Greatest Inventions for 2007 by warfighters in theater.

The Picatinny Blast Shield (PBS) was rapidly developed, qualified, and fielded in response to a USMC Light Artillery Vehicle (LAV) Operational Advisory Group (LOAG) requirement for survivability upgrades on Marine light tactical vehicles. Delivered in late 2006, the PBS provides constant flank protection while maintaining the M240 machine gun filed of fire and is positioned and angled for maximum IED blast deflection. A lightweight, modular kit that uses existing attachment points, it can be installed in the field in 30 minutes without special tools. The PBS was also voted one of the Army’s Top Ten Greatest Inventions for 2007.

In early 2007, a quantity of O-GPK were delivered to the Multi-National Corps-Iraq (MNC-I) in Balad, Iraq that had been adapted for the RG-31, which uses a modified Platt Systems 660mm ring mount. This version also supports a number of Army-supplied weapons and mounts including the MK93 cradle, M2, MK19, M240B, and M249.

The O-GPK has since been adapted for the RG-33 and MRAP vehicles. Enhancements in development include a "bolt-on" overhead protective cover that provides further protection and concealment from overhead attacks and elevated sniper threats. The universal design of the overhead cover ensures its adaptability to a number of vehicle platforms (including HMMWV, RG-31, RG-33, and MRAP). The use of advanced materials like titanium ensures that the cover weight will meet user requirements.

**SOCOM Titanium-Based O-GPK**

In February 2007 ARDEC initiated a design proposal based on a request from SOCOM for an O-GPK outfitted for Special Operations Forces (SOF) purposes. Modifications included changes to the turret size and amount of transparent armor and accommodation for additional SOF weapons. A critical requirement was that the combined turret and shield weight not exceed 400 lbs. Based on its extensive prototyping and development work with titanium, ARDEC recommended entirely replacing the O-GPK’s steel with the lightweight metal. Titanium is up to 30% lighter than steel in ballistic applications, providing good multi-hit capability and performance across a wide range of ballistic threats. Low Rate Initial Production (LRIP) was initiated in June 2007 and 110 units delivered.

**TITANIUM PROCESSES AND PRODUCTION EQUIPMENT**

ARDEC has adapted and refined various manufacturing methods (casting, forming, powder metallurgy, joining, and machining) to automate processes and improve technologies to make it easier and more cost effective to use titanium in military applications. With its practice of ensuring that designs are manufacturable early in the development process, ARDEC has collected a body of technical information about titanium that has been communicated to the U.S. industrial base in the form of Technical Data Packages (TDPs).

**Titanium Technology Advances**

Among the titanium technology advances ARDEC has participated in are: the design and construction of a high-rate, continuous-melt titanium furnace; developing techniques for using more low-cost input materials in titanium production; reducing overall cost by reducing production cycles time and lead times; and testing and validating the single-melt processing of extruded shapes. ARDEC has also participated in several DARPA-funded initiatives to develop alternative titanium extraction processes that are faster and more cost effective than the traditional Kroll method. It has also validated welding configurations for single-melt ballistic performance and, with the American Welding Society, published a new titanium structural welding code. Titanium robotic welding technology has been validated for structural and ballistic applications and transferred to industrial base production facilities.

Single-melt processing advances include the use of a plasma arc melting torch plus a secondary torch to produce continuous casting of near-net-shape round or rectangular ingots. This alternative to vacuum arc remelting reduces the number of processing steps for producing a titanium ingot, which lowers the cost associated with rolling to plate. Plasma arc melting allows the input material to be up to 90 percent scrap, which can drive down overall production.
costs by as much as 30 percent. Single-melt processing also reduces cycle time as much as 50 percent and can shave up to 60 days off of production lead times.

**Titanium Extraction Advances**

ARDEC is keenly interested in extraction alternatives that offer improvements over the traditional Kroll titanium extraction process.

**Fray-Farthing-Chen (FFC) Cambridge Process**
The FFC Cambridge process is an electrochemical method that reduces solid metal oxide to metal in a molten salt. This single-extraction process produces various metal alloys directly from mixed metal oxide powders without melting. It uses approximately 1.67 pounds titanium dioxide (TiO₂) feedstock to make one pound of titanium metal. The FFC Cambridge process produces titanium in powder or sponge form. Its simpler operation has a low environmental impact and reduces energy and operating costs.

**Armstrong Process**
The Armstrong process, developed by International Titanium Powder (ITP), of Lockport, IL with DARPA funding, uses the continuous reduction of TiCl₄ vapor in a molten sodium stream to produce an extremely pure titanium and NaCl mixture. This results in a small-diameter, high-purity metal powder that can be processed at a fraction of the cost of titanium sponge. Also environmentally friendly, the Armstrong process operates in batch-continuous mode with virtually no waste.

**MER Process**
An electrochemical reduction that uses an anode comprised of TiO₂ and a reducing agent to produce low-cost titanium metal in powdered, flaked, or solid form, the MER process was developed by the Material and Electrochemical Research (MER) Corporation, of Tucson, AZ (with DARPA funding). MER processing makes titanium metal powder that can be directly formed into desired shapes, allowing manufacturers to make parts faster, with less machining, and with significantly less scrap.

**Welding Advances**
Advances in pulsed gas metal arc welding (GMAW-P), which involve modifying existing practices to optimize them for titanium, have turned welding titanium into a high-productivity automated (robotic) process. Welds can be performed up to ten times faster than the linear travel speed of manual gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding. Welds normally requiring three manual passes can be performed in a single pass. Two waveform templates are used: a single-pulse GMAW-P that uses a 100 percent helium shielding gas and provides good penetration capability; and a "double-pulse" template, consisting of a short duration "exciting" pulse followed by a second peak "detaching" pulse for metal transfer. These improvements yield higher quality, less expensive welds.

**CONCLUSION**
The U.S. Army history of developing titanium armor solutions includes the evolution of gunner protection design from the lightweight Stryker Cupola Shield to the SOCOM Objective Gunner Protection Kit. The titanium O-GPK, based on a design voted one of the Army’s Top Ten Inventions for 2007, satisfied SOCOM requirements for minimum added weight and maximum force protection. The Army continues to seek titanium processing advances that lower cost and make titanium more readily available to current and future weapons systems.

**CONTACT**
Stephen Luckowski
Chief, Materials Manufacturing and Prototype Technology
US Army ARDEC
Building 3150
Picatinny Arsenal, NJ 07806-5000
P(973)724-3100
F(973)724-5531
stephen.luckowski@us.army.mil

Jeffrey Schutz
Materials Engineer, Materials Manufacturing and Prototype Technology
US Army ARDEC
Building 3150
Picatinny Arsenal, NJ 07806-5000
P(973)724-5333/(973)724-5752
F(973)724-4525
jeffrey.schutz@us.army.mil
New Titanium Armor Application Provides Protection in a Lightweight Kit

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Stephen Luckowski
Chief, Materials, Manufacturing and Prototype Technology
Chairman, American Welding Society - Structural Titanium Welding Code

Jeffrey Schutz
Materials Engineer
Providing the lethality technology for over 90% of the Army’s munitions

- ARDEC (all sites) ~ 3098
  - Picatinny Arsenal = 2648
  - Benet (Watervliet Arsenal) = 240
  - Rock Island Arsenal = 145
  - Adelphi & APG = 65
- S&E average 20 years experience – more than 30,000 man-years of highly specialized experience in critical multidisciplinary field (no commercial equivalent)
- S&E new hires from Apr 99 to Jan 07 = 994
- Intellectual Property (FY07):
  - Invention Disclosures – 49
  - Patent Applications – 30
  - Patents Issued – 13
- Patent License Agreements = 13
- Growth and success through Cooperative Research and Development Agreement (CRADA) = 159
- World recognized armaments authority

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.
Supporting GWOT: The Evolution of Gunner Protection

2005: Stryker Cupola Shield
Fielded: Over 600 kits
Platform: Stryker, ASV Knight

2007: RG31 O-GPK
Fielded: Over 327 kits
Platform: RG-31

2006: Objective Gunner Protection Kit (O-GPK)
Fielded: Over 30,000 kits
Platform: Humvee, MRAP

2007: SOCOM O-GPK
Fielded: Over 200 kits
Platform: Humvee

2006: Picatinny Blast Shield (PBS)
Fielded: Over 250 kits
Platform: USMC LAV

2008: O-GPK Enhancements
Fielded: 20,000 planned
Platform: Humvee, MRAP

 TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.
• Stryker Fire Support Vehicles (FSV) and Recon Vehicles (RV) lacked vehicle commander protection
• ARDEC leveraged titanium technologies to design/prototype cupola shield for high-rate production
• 400 kits delivered to OIF field units (March 2005)
• Titanium-based shield enhances survivability while improving operation and performance
Gunner Protection Kits (O-GPKs)

- ARDEC rapidly developed/fielded enhanced protective solutions for combat vehicles with transparent armor
  - ARDEC engineers and FAST team determined requirements Dec 2005

- Built on prior successes in rapid development and delivery
  - Designed concurrent with manufacturing engineering to speed development and fielding
  - Prototyped in-house using production-ready processes
  - Delivered for testing Jan 2006
• Verified and tested by ARDEC, Aberdeen, PM-TV, TARDEC
• LRIP to OIF: initial 1,000 in Jul 2006
• Army depot production — 15,000+ O-GPKs for M1114
• New standard O-GPK meets warfighter force protection needs
• Awarded Army’s Top Ten Greatest Inventions for 2007
- Awarded Army’s Top Ten Greatest Inventions for 2007
- ARDEC-developed low-weight blast shields give vehicle commander enhanced protection
  - Positioned and angled for maximum IED blast deflection
- Minimizes weight and components to meet turret weight requirements
- Uses existing attachment points, proven ballistic materials and common manufacturing processes
- Installs in 30 minutes with no special tools
  - Modular kits proven producible and affordable with government-owned Technical Data Package (TDP)
• Rapidly integrated O-GPK onto RG-31 platform
• Provides 360° visibility and protection from common threats
• Enhanced protection and visibility for engineering units
• Works with modified Platt Systems 660mm ring mount
• Uses Army-supplied weapons and mounts (Mk-93 cradle, M2, Mk-19, M240B, M249)
• ARDEC managed production of O-GPK kits and ring mount procurement
• Delivered initial units to Balad, Iraq early 2007
Overhead Protective Cover

- “Bolt-on” capability to existing turret shield includes concealment and ballistic protection from overhead attacks or elevated sniper threats
- Universal design ensures adaptability to multiple vehicle platforms (HMMWV, RG-31, RG-33, MRAP)
- Advanced materials ensure weight can meet user requirements
• The Stryker Cupola Shield ushered in a new era of opportunity for using titanium on US Army vehicles.
• Weight, not cost, was the driving factor in choosing titanium.
• Since the Bradley Hatch and M777, ARDEC has done significant technology work to make titanium more applicable and affordable.

Courtesy of National Energy Technology Laboratory (NETL)
The Army’s primary requirement is typically speed – the need for rapid procurement and large quantities make steel a logical choice for producing SOCOM GPKs.

For some customers, such as SOCOM, weight (not cost) is the key factor in choosing a titanium solution. These are “cost-independent” customers.
USASOC Requirements Drive Titanium GPK Development

• SOCOM GPK requirement received August, 2007
• Designed and prototyped by ARDEC
• First fielded in January, 2007
• To date, over 200 kits delivered to Iraq and Afghanistan
USASOC Requirements Drive Titanium GPK Development

- In January, 2007 USASOC had urgent request for customized SOCOM GPK to meet additional SOF needs
  - Weight reduction
  - Secondary weapons
  - Additional transparent armor
- Titanium was determined to be the most effective material to meet performance and weight goals
  - Goal: turret and shield not to exceed 400 lbs; approximately half the weight of standard O-GPK
- ARDEC completed USASOC titanium GPK design in February, 2008
- To date, over 125 titanium GPKs have been delivered
Why Use Titanium?

• Titanium reduces weight
  – Up to 30% lighter than steel in ballistic applications
  – Meets requirements for transportability

• Titanium provides superior protection
  – Good multi-hit capability and performance across wide range of ballistic threats
  – Improves survivability

• Titanium components support adding other capabilities without increasing overall vehicle weight

• ARDEC has a proven titanium track record
  – Prototyping vehicle “up-armor”
    • Stryker Cupola Shield for Fire Support/Recon vehicles
    • Stryker MCV-B bay doors and engine cover
  – Advancing manufacturing/cost-reduction technologies
    • Extraction, production and processing methods
    • Machining/bending/welding
    • Published the American Welding Society “D1.9 Structural Welding Code—Titanium” in July 2007
• SOCOM urgent need required rapid response from industry
• Initial quantities received within 10 weeks of request
• Total titanium to be delivered – ¼ million lbs

Allegheny Technologies
Building the World's Best Specialty Metals Company™

RTI International Metals, Inc.

TIMET®

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.
• ARDEC modeled all bending up front to reduce manufacturing time
• Predicted forming load and springback in Ti-6Al-4V plate bending processes
SOCOM O-GPK Bend Modeling

Ti-6Al-4V plate bending load

Load (metric ton/in)

Punch stroke (in)

Step 1

Damage

0.227

0.151

0.0757

0.000 Min

0.000 Max
SOCOM O-GPK Bend Modeling

Loading (stroke 1.15 in)
Bend angle : 62.2°

Unloading
Bend angle : 51.3°
Springback consistent across different punch stroke loads.
SOCOM O-GPK Bending
• Cut pieces were pre-heated on bend axes to minimize cracks
• Heat induced springback in addition to inherent springback of titanium material
• Bending temperatures kept as low as possible (between 800 – 1000°)
• Titanium assembly brackets required a different set of bending data
• Production process further refined with the introduction of induction heating system
• More controlled, consistent heating of material across the entire bend area
• Significantly reduces bending time
• Titanium is a key material to meet the US Army’s goal of a highly survivable force
• Gunner Protection Kits (GPKs):
  – Army-wide solution
  – Steel → Titanium
  – Won Army Top 10 Invention of 2007
• Titanium GPK satisfied SOCOM’s requirements for weight and protection
• Material analysis of titanium allowed ARDEC to reduce the production time and cost
• Manufacturing technology advances help lower cost & make titanium more readily available to weapons systems
Question To The Industry:

“When can we provide more military-grade titanium for the ‘big’ Army?”