U.S. ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND

Materials and Manufacturing Advancements to Demonstrate Objective Underbody Protection

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BACKGROUND: UNDERBODY THREAT

WWII

Korea

Vietnam

OIF

OEF

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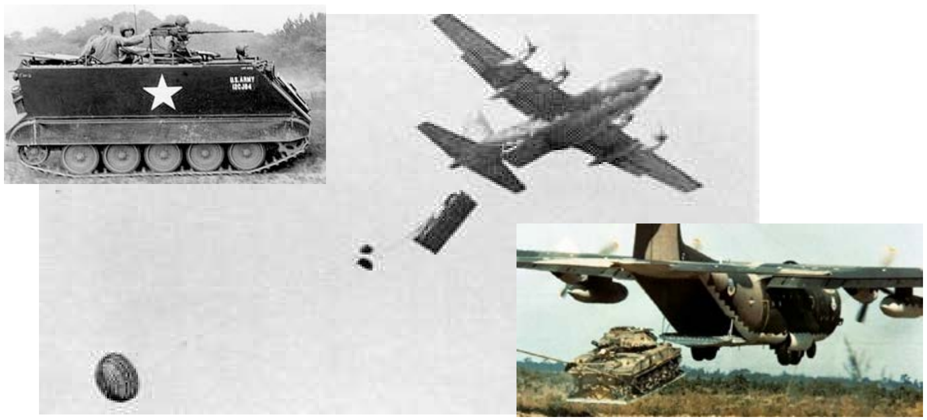
BACKGROUND

1950’s: Requirements for Aluminum Hull Combat Vehicles



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Ballistic Design Requirements for Mobile Vehicles

Substantial Protection Feasible
- Small Arms Rifles and Machine Gun
- Fragments from High Explosive, Shell
- Mortars
- Anti-Personnel Mines

Substantial Protection Impractical
- Artillery Kinetic Energy Projectiles (AP)
- Shaped Charge (HEAT)
- High Explosive Plastic (HEP)
- Anti-Tank Mines
- Nuclear

1960’s: Deployed to Vietnam

https://www.awm.gov.au/collection/C243013

http://sitrep1.tripod.com/members_photo_album/Erik_Frisken.jpg

Between November 1967 and March 1970… mines accounted for 73% of all vehicle losses, including 1,342 M113s.

(Armor Magazine, Nuckols and Cameron, 2016)

While requirements did change from the 1950s to the 1980s, they were insufficient for operationally relevant threats seen in OIF/OEF.

US ARMY AFFORDABLE PROTECTION FROM OBJECTIVE THREATS (APOT) MANTECH PROGRAM

OBJECTIVE

Mature affordable aluminum hull manufacturing technologies to defeat objective underbody blast threats and demonstrate objective level force protection.

Definition:

- APOT Threshold (T) > Operationally Relevant Threat
- APOT Objective (O) >> Operationally Relevant Threat

OPPORTUNITIES ADDRESSED

- ***Limited Manufacturing Technologies***
  - Current manufacturing technologies not mature enough to fabricate heavily protected combat vehicle structures
- ***Force Protection***
  - Fielded solutions not sufficient to protect against objective underbody blast attacks
  - Objective underbody threats require thicker hull materials and new design concepts
- ***Informed Decision Making** via Live Fire Tests*
  - Objective threats far exceeded prior understanding of structure performance
  - Understand the realm of “possibilities”

APOT HULL MANUFACTURING

Minimize the propensity of common failure modes in aluminum hulls by maturation of manufacturing methods for thicker hulls

- Having minimal welds through the use of forging and forming;
- Utilizing improved weld processes for higher strength welds with minimal defects.

FORGING

FORMING

From Steel News, 2015

HIGH ENERGY BURIED ARC WELDING (HEBAW)

MATERIAL CONSIDERATIONS: ARMOR ALLOYS FOR FORGING / FORMING

PEO-Ground Combat Systems: Conventionally weld-able, non-proprietary alloys

Alloy	MIL DTL	Pros	Cons
5083	46027K	Weldable, Extensive experience	Forge-ability constaints, Limited strength in thick section forgings
5059	46027K	Weldable, higher strength than 5083	Same as above, Proprietary
6061	32262	Forgeable, inexpensive	Poor strength in thick section, not qualified for ballistic welds
2219	46118E	Can forge large sections	Low elongation GMAW welds, little historical armor utilization
2519	46192C	High strength, can forge large sections	Low elongation GMAW welds, blast performance concerns
2139	32431	High strength, high toughness, good blast resistance	Low elongation GMAW welds Proprietary,
7085	32375	High strength, high toughness, good blast resistance, utilized for thick section forgings	Conventionally un-weldable, Proprietary.
7039	46063H	High strength	Stress corrosion cracking, blast resistance in T6 temper
7017	*32505*	High Strength	Stress corrosion cracking, blast resistance in T6 temper
7020	*32505*	Forge-able, capable of very thick sections, moderate strength, good toughness, weldable, Investigated as part of FTAS program	Appropriate temper required to minimize stress corrosion cracking

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ALUMINUM 7020 FOR FORMING & FORGING

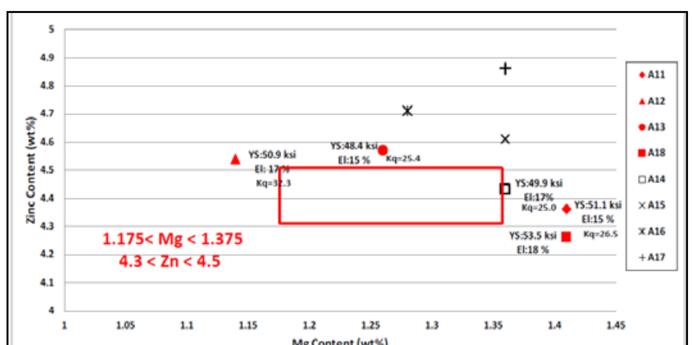
- Weld-able by conventional means
- Forge-able - thick section forgings produced by Aubert-Duval (France)
- Commodity armor alloy produced in Europe by Aleris, Constellium, Alcoa (UK) – but *never commercially produced in the US!*

ARL worked with ATI, Vista Metals and Constellium to quickly develop industrial scale processing parameters for domestic casting, forging and plate production

Developed target chemistry, homogenization practice, solution heat treat, quench and ageing practice.

ATI Inc.
Alloy Technology Innovations

7020 Chemistry and Thermomechanical Process Parameters Developed using Small Forgings



Very large billet casting done by Vista Metals.

VISTA METALS

FORGED HULL – CONCEPT TO COMPONENT

Risks

- Thickness distribution
- Geometry
- Component depth
- Lack of cold workability
- Ingot size and shape limits
- Ingot upsetting
- Preforming
- Process parameters
    - Temperature (piece/tool)
    - Tooling
    - Material handling
- Material Flow characteristics
- Residual stresses
- Quench Sensitivity
- Ingot chemistry
- Weld performance
- Side wall fill
- Die configuration
- SHT&Q parameters
- Ageing parameters
- Equipment limitations
- Machining distortions

Activities

- Component Design
- Design for manufacture
- Tool steel acuisition
- Forging analysis
- Tooling design
- Tooling fabrication
- Chemistry development
- Ingot acquisition
- Ingot upsetting
- Process flowpath
- Risk assessment/mitigation
- Preforming
- Die forging
- Component clean-up
- Residual stress analysis
- Distortion analysis/mitigation
- SHTQ & Age
- Straightening
- Machining
- Shipping
- Integration (Bob Sled, BH&T)
- Blast testing

From this…

…to this in 12 months!

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FORMED HULL – CONCEPT TO COMPONENT

Constellium Capable of very large plate production for forming single piece hulls

- Rapidly developed the US ingot casting and rolling parameters for aluminum alloy 7020 production at Ravenswood, WV
- Produced all 7020-T651 plate for the effort.
- Produced the largest aluminum armor plate ever for formed hull trials.

From this…

Risks

- Geometry
- Bend radius/thickness limits
- Formability vs. ageing
- Material flow characteristics
- Residual stresses
- Weld performance
- Die configuration
- SHT&Q parameters
- Ageing parameters
- Press limitations
- Machining distortions

Activities

- Design for manufacture
- Forming analysis
- Die design / manufacture
- Ingot processing
- Process flow path
- Risk assessment/mitigation
- Residual stress analysis
- Forming
- Machining
- SHTQ & Age
- Shipping
- Integration (Bob Sled, BH&T)
- Blast testing

AMRO FABRICATING CORPORATION

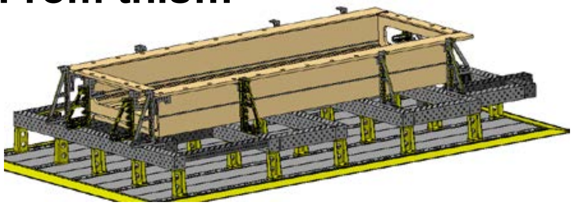
HIGH ENERGY BURIED ARC WELDED (HEBAW) HULL – CONCEPT TO COMPONENT

HEBAW

- BAE has developed an automated, high current density gas metal arc welding (GMAW) technology for 5083 and 5059 alloys

- HEBAW advantages of conventional GMAW processes
    - High deposition rate (70-90% reduction in number of weld passes)
    - High weld penetration
    - 90% reduction in weld time
    - Reduced filler metal required
    - Less heat input → less distortion
    - Robotic – controlled, repeatable
    - Reduced weld defects

From this…



Thickest welded aluminum hull ever fabricated

MANUFACTURING TECHNOLOGY ACHIEVEMENTS

Forged

Largest aluminum die forging ever produced

Forge hulls capable of integrated O protection

- Forged lower hull successfully manufactured and tested at O
- Forged Ballistic Hull & Turret (BH&T) fabricated; tested at O
- Integrate Tencate Active Blast Defense System (ABDS) into BH&T and re-tested at O
- Integrate Sloman Active Blast & Ballistic System (ABBS) onto BH&T and re-re-tested at O
- Machine forged lower hull to reduced areal density, test at T

Formed

First formed aluminum tracked combat vehicle hull produced

Form hulls having integrated T, kit to O protection

- Formed lower hull successfully manufactured and tested at T
- Formed lower hull + kit successfully manufactured and tested at O
- Fabricate formed BH&T and test at O

Welded

Thickest welded lower combat vehicle hull ever produced

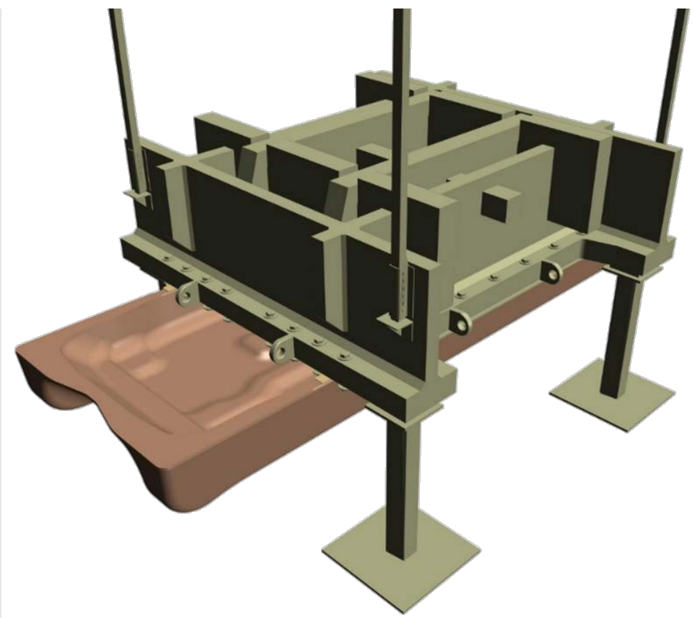
High Energy Buried Arc Weld (HEBAW) hulls having integrated T, kit to O

- HEBAW hull successfully manufactured and tested at T
- HEBAW hull + kit successfully manufactured and tested at O
- HEBAW tested (on weld) at T

9 full scale lower hull structures, including 2 ballistic hull & turrets (BH&Ts), fabricated and tested. Demonstrated T and O underbody blast resistance!

LIVE FIRE TESTING OF HULLS

All hulls were mounted on a massive (44 ton) test fixture (the Bobsled) and tested with both Threshold and Objective underbody charges to validate the performance of the manufactured hulls.



HULL BLAST RESULTS

MANUFACTURING PATH	POST-TEST HULL	OBSERVATION
Forging		Minimal permanent deformation
Forming		~Minimal permanent deformation
HEBAW		Moderate permanent deformation

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BALLISTIC HULL AND TURRETS (BH&T'S)

- The formed and the forged hulls were manufactured into BH&Ts
- The BH&Ts were outfitted with a number of energy absorbing technologies, ATDs and instrumentation.
- BH&T's were live fire tested at Objective underbody levels.
- Force protection was demonstrated.

SUMMARY

•The Affordable Protection from Objective Threats (APOT) ManTech effort matured three manufacturing processes for lower hulls having
•Objective level blast resistance and validated the processes and resultant hulls through live fire testing.

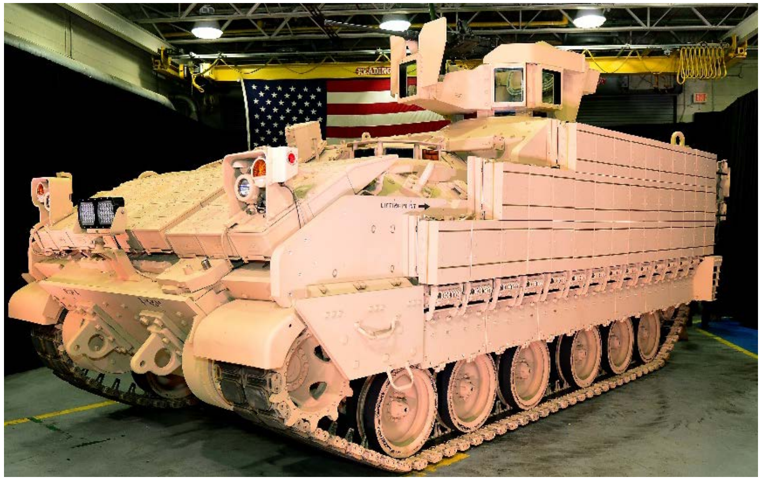
•Through collaboration of multiple agencies, nations and small and large businesses, a number of DoD efforts were aligned to develop and demonstrate Objective level underbody blast protection.

•Results were transitioned to TARDEC, PEO Ground Combat Systems, US Army TRADOC and vehicle OEMs.

TRANSITION & IMPLEMENTATION

- TRADOC Maneuver Center of Excellence wrote requirements based on the results demonstrated as part of APOT.

- BAE implemented design elements and manufacturing processes matured as part of APOT into the Armored Multi-purpose Vehicle (AMPV) lower hull.



https://www.baesystems.com/en-us/multimedia/armored-multi-purpose-vehicle-roll-out

ACKNOWLEDGEMENTS