Advanced Lightweight Armor Technology

Encapsulated Ceramic Armor System

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INEEL Home of Science and Engineering Solutions

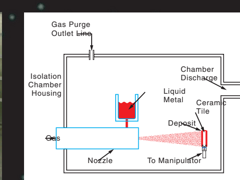
Encapsulated Ceramic Armor System has great potential for improved ballistic and multiple-hit performances and has been identified as one of the potential base armor systems for the Future Combat Systems and the Objective Force vehicles. Considerable efforts have been devoted to improve the armor system design and to the selection of appropriate high performance materials. Concurrent efforts have been focused on the development of advanced manufacturing technologies to increase the manufacturing throughput, reduce cost and the possibility to manufacture the final system in a net-shape. The INEEL research team has developed a unique spray forming process to form the encapsulating structure around an advanced ceramic core, such as silicon carbide and fiber-reinforced silicon carbide composite, in a single step. Depending on the material utilized, the developed spray forming process has an added advantage of producing structural confinement, which has improved material properties resulting from the fine-spraying process. This often yields a stronger and tougher final material than the starting material. The spray form process is described. This unique manufacturing technology is demonstrated with the fabrication of several prototypes and the ballistic test results of these prototypes are reported and discussed.

Conventional Manufacturing Methods for Encapsulated Armor System

- Machining, electron-beam welding and hot-isostatic-press (HIP) - slow, expensive and flat panel system only
- Other manufacturing methods under investigation: Powder metallurgy, squeeze-casting, direct Laser deposition

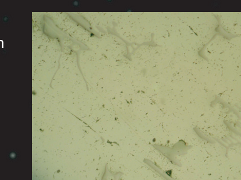
Present Approach

- Superheated molten metal is injected into a custom atomizer.
- Atomization increases surface area by 10 orders of magnitude.
- Convection heat transfer rate of about 10^4 W/m^2K rapidly cools metal, resulting in a combination of liquid, solid, and "slushy" droplets that are deposited onto a ceramic core, encapsulating the core.
- Deposited material is about 70% solid. Liquid fraction allows material to "weld" together forming a coherent solid. High solids fraction limits metal shrinkage, preventing damage to the ceramic core.
- Process takes place in closed chambers purged with nitrogen to prevent oxide inclusion defects.

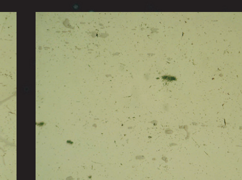


Microstructure of 5083 Al

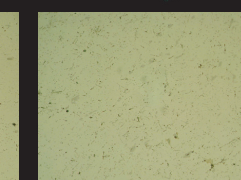
- In-flight convection cooling teams with conduction cooling at the substrate to rapidly solidify the metal.
- Non-equilibrium solidification.
  - Extended solid solubility.
  - Very limited segregation.
  - Equiaxed grain formation.
- Constituent-phase particle sizes are somewhat finer than those found in wrought commercial material and significantly finer than in cast alloy.



Cast 5083



Wrought 5083



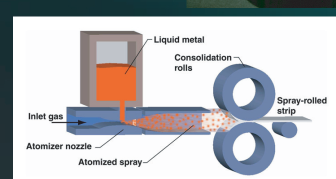
Spray-formed 5083

Tensile Properties of 5083 Al

Condition	Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation at Failure (%)
Commercial-annealed (0 temper)	42(40)	21(18)	22(16)
As spray formed	40	32	8
Spray formed-annealed (530°C, 10 min.)	38	19	20
Spray formed-annealed (530°C, 30 min.)	43	19	30
Spray formed-annealed (530°C, 1 hr.)	44	18	31
Spray formed-annealed (530°C, 2 hr.)	43	19	34
Spray formed-annealed (530°C, 4 hr.)	44	19	34
Spray formed-annealed (530°C, 8 hr.)	44	20	37

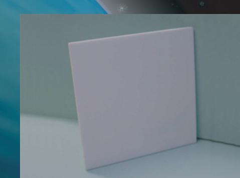
INEEL Spray Forming

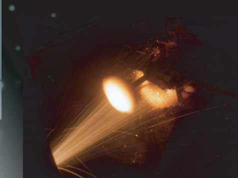
- Unique, patented technology involving gas atomization of metals, in-flight convection cooling, followed by deposition of droplets onto substrates.
- Combines rapid solidification processing with near-net-shape materials processing.
- Broad range of product applications.
- Current focus is on armor, tooling (molds and dies), and aluminum strip.



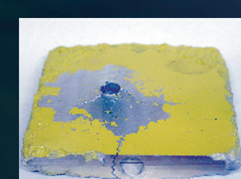
Processing Steps – Prototype Encapsulated Armor System

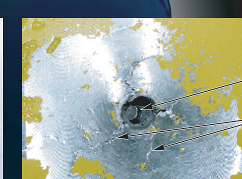
- 1/8" thick CoorsTek AD90 alumina tile was manipulated in a dense spray of atomized 5083 aluminum.
- Deposit was machined to 1/8" front thickness, 1/4"side thickness, and 1/4" back thickness.
- Deposit was annealed using a standard procedure prior to ballistic testing.



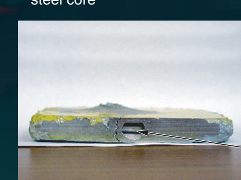


7.62 x 39 mm steel core





Front



Side

Back

Test Parameters

- MIL-STD-662 setup
- Test rounds: 7.62 x 39 mm 1943 PS, steel core
- Test velocity: 2380 ft/sec
- Muzzle to target distance: 20.5 ft
- Three-stations light screen velocity sensor
- Yaw card 6" in front of target face

Spray-form Encapsulated Armor Prototype

Objectives:

1. Lightweight system
2. Multiple-hit
3. High throughput, low cost
4. Line-of-Sight Areal Density ~ 8 lb/sq ft

Technical and Economic Benefits

- *Versatile armor-forming approach*
  - *Process does not depend on the shape of the ceramic, allowing ceramics with optimized geometry to be encapsulated.*
  - *Suitable for nearly any alloy.*
  - *Suitable for all ceramics.*
  - *Encapsulating phase can be a monolithic metal or a particulate-reinforced metal matrix composite.*
- *High production rate*
  - *Aluminum: about 1200 lbs/hr with bench-scale system.*
  - *Steel: about 500 lbs/hr with bench-scale system.*
- *Property improvement through rapid solidification of metal phase*
- *Scalable to accommodate large armor systems*

Conclusion

- *Unique spray forming technology was successfully employed in manufacturing encapsulated ceramic armor prototype*
- *Prototype armor system successfully defeated threat*
- *Prototype armor system demonstrated multi-hit capability*

Future R&D Directions

- *Optimization of system configuration*
- *Other ceramic materials: SiC, B_4C, TiB_2*
- *Other encapsulation materials: 7039Al, 2195Al-Li, steels, Ti alloy*
- *Functionally graded encapsulation*
- *System scale-up for higher threats*
- *Curvilinear system geometry*